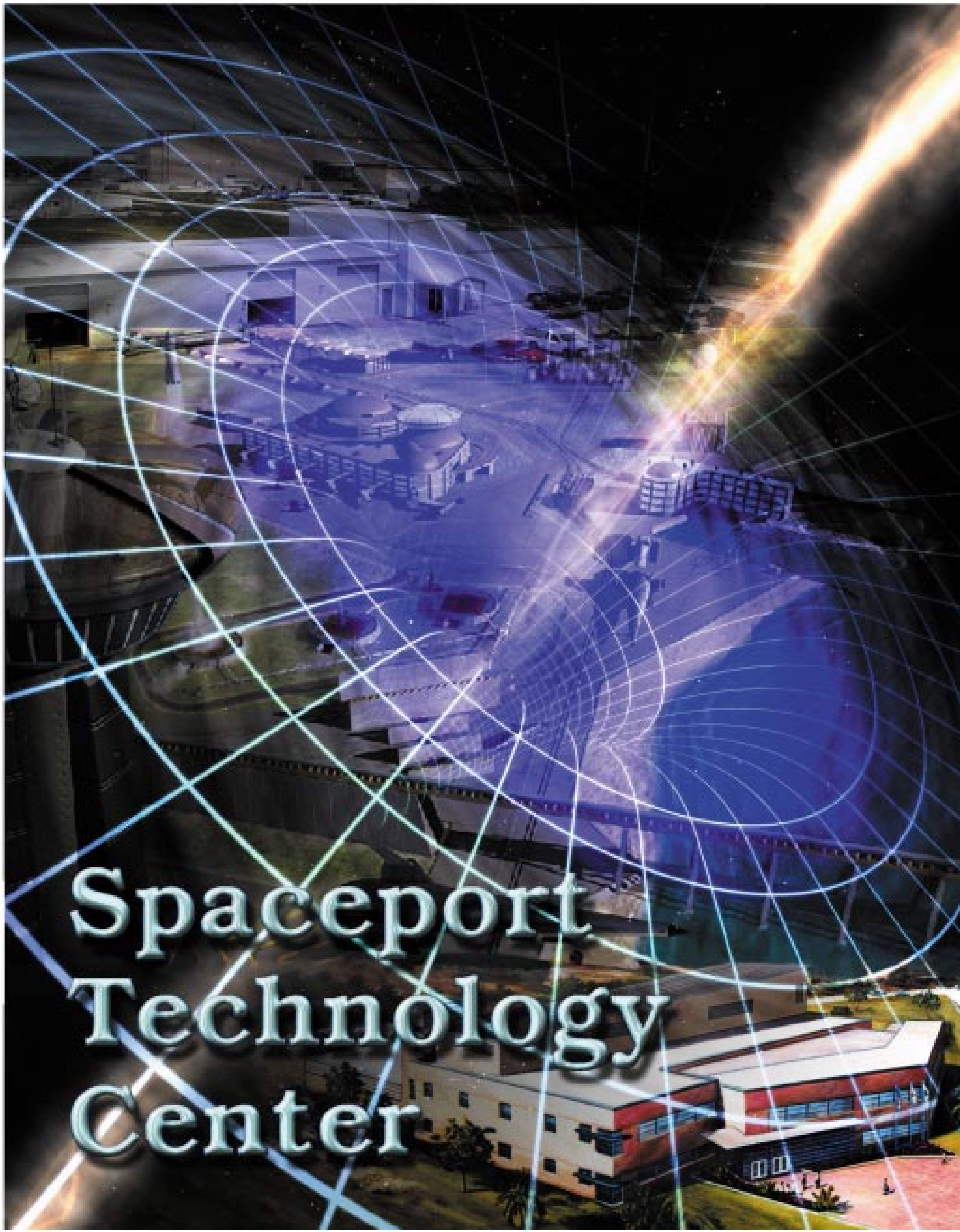
NASA Technical Memorandum 208567

Research and Technology 1999 Annual Report

John F. Kennedy Space Center



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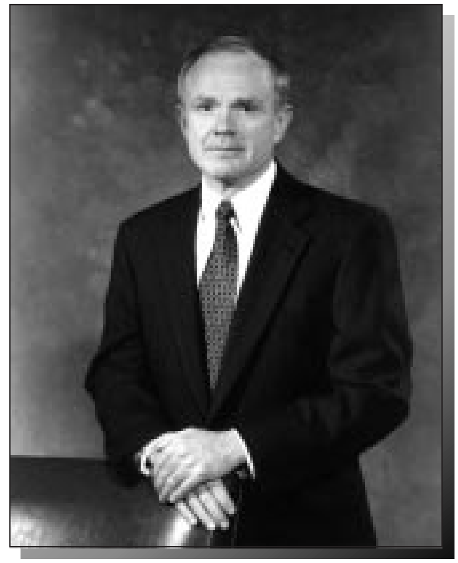
Foreword



As the NASA Center responsible for preparing and launching space missions, the John F. Kennedy Space Center (KSC) is placing increasing emphasis on its advanced technology development program. To focus our effort, we have created a Spaceport Technology Center concept with a range of technology developments that will assist us to reduce the cost of access to space and enable greater commercial success of our space launch industry. Our technology development encompasses the efforts of the entire KSC team, consisting of Government and contractor personnel, working in partnership with academic institutions and commercial industry. This edition of the KSC Research and Technology 1999 Annual Report covers the efforts of these contributors to the KSC advanced technology development program, as well as our technology transfer activities.

James Aliberti, Chief of KSC's Technology Programs and Commercialization organization, (321) 867-6224, is responsible for publication of this report and should be contacted for any desired information regarding the advanced technology program.

Roy D. Bridges, Jr.
Director

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Technology Programs and Commercialization

Introduction

The John F. Kennedy Space Center's (KSC) outstanding record of achievements has earned it an honored place in history and an essential role in Space Transportation today. As NASA's Center of Excellence for Launch and Payload Processing Systems, KSC is increasing the momentum in space-faring technology development for current and future spaceports. The Spaceport Technology Center (STC) concept carries out KSC's role within NASA to meet the goals of increased safety, reduced cost of space access, and rapid expansion of commercial markets by infusing spaceport technologies into all facets of Space Transportation Systems.

KSC's historic background as the nation's premier launch facility creates an ideal environment for the STC. The STC's knowledge, expertise, facilities, and equipment provide technologies and processes to customers who propose to build and operate spaceports on Earth, Moon, Mars, and beyond. The STC is composed of the three pillars that are the foundation of a spaceport: **Launch and Launch Vehicle Processing Systems, Payload and Payload Carrier Processing Systems, and Landing and Recovery Systems**. KSC has unparalleled expertise in designing, building, and operating a spaceport with all its complex systems. KSC's leadership in incorporating safer, faster, cheaper, and more-robust systems and technologies will pave the way for the future space industry.

The thrust of the STC technology development is concentrated in five areas referred to as Spaceport Technology Development Initiatives (STDIs): **Command, Control, and Monitor Systems; Range Technologies; Fluids and Fluid Systems; Materials Evaluation; and Process Engineering**. KSC is developing technologies for spaceport architecture and innovative techniques that will reduce the costs of ground processing and minimize the life cycle costs of space transportation.

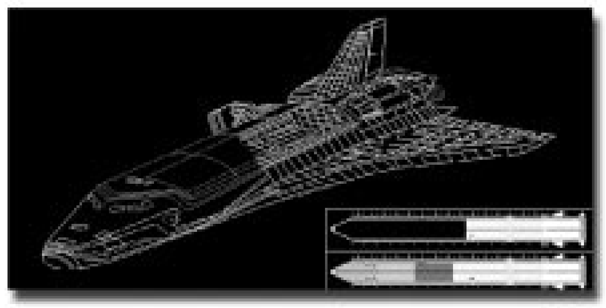
KSC aggressively seeks industry participation and collaboration in its research and technology development initiatives. KSC also seeks to transfer its expertise and technology to the commercial sector and academic community. Programs and commercialization opportunities available to American industries and other institutional organizations are described in the Technology programs and Commercialization Office Internet Web site at *http://technology.ksc.nasa.gov*. Additional insight into KSC's Spaceport Technology Center can be found at *http://www-pao.ksc.nasa.gov/kscpao/spacetech/*.

Section I

Spaceport Technology Development Initiatives

- Command, Control, and Monitor Systems
- Fluids and Fluid Systems
- Materials Evaluation
- Process Engineering
- Range Technologies

Command, Control, and Monitor Systems



Navigation and Landing Aids Laboratory

KSC's Navigation and Landing Aids Laboratory is one of several facilities operated by the KSC Engineering Development Directorate. The laboratory was created initially to support the Space Shuttle program requirement to certify the accuracy of the navigation systems the orbiter uses to find and land at designated sites. This effort lead the laboratory into development of Global Positioning System (GPS) applications, like the X-34 Reusable Launch Vehicle's (RLV's) ground-based Differential GPS (DGPS) and other research and development projects for the KSC Weather Office.

Following reentry at an altitude of up to 145,000 feet, the Tactical Air Navigation (TACAN) system on the ground provides range and bearing measurements to the orbiter. When the orbiter is on the runway heading at an altitude of 18,000 to 20,000 feet, more precise guidance signals on slant range, azimuth, and elevation come from the Microwave Scanning Beam Landing System (MSBLS). It is the responsibility of KSC's Shuttle Navigation group to certify the accuracy of the two systems by performing flight checks using an instrumented aircraft.

The Navigation and Landing Aids Laboratory was responsible for the design of the system hardware and software, fabrication of the workstations, and the test and implementation of the Flight Inspection System for the flight checks at Continental United States (CONUS) and Transatlantic Abort Landing (TAL) landing sites. The heart of the system is a Carrier Phase Differential GPS that is accurate to within 10 centimeters in three dimensions. The Flight Inspection System is designed to fly in either a C-130 Hercules or the KC-135 microgravity aircraft. Use of the computer-based GPS Flight Inspection System has reduced the time to certify a typical Shuttle landing site from weeks to an average of 3 days.

MSBLS Flight Inspection System

The X-34 is an unmanned, technology demonstrator of an RLV that is dropped from a mother plane, flies to a low Earth orbit, returns to Earth, and lands, all autonomously. The X-34 vehicle uses the same DGPS technology as the Shuttle's MSBLS Flight Inspection System to provide precision navigation during the landing phase. DGPS utilizes a "base station" with a GPS receiver located on a previously surveyed marker to calculate the position errors coming from the GPS satellite constellation in real time. Corrections to these position errors are transmitted to GPS receivers in the surrounding area called "rovers." The rovers use these corrections when calculating their positions and, thereby, gain a higher degree of accuracy.

In the case of the MSBLS flight checks, the rover is the instrumented aircraft; for the X-34 it is the vehicle itself. In cooperation with the X-34 prime contractor, Orbital Sciences Corporation, the Navigation and Landing Aids Laboratory built a dual-channel DGPS base station tailored to the X-34 requirements for redundancy, reliability, and built-in monitoring. The first two systems are currently deployed to Dryden Flight Research Center to support the initial phase of X-34 testing at Edwards Air Force Base.

X-34 DGPS

In order to support the future Spaceport requirements, as identified by the KSC Range Development Project, the Navigation and Landing Aids Laboratory has received funding to purchase a state-of-the-art GPS simulator. This versatile testing tool will provide the laboratory and KSC the capability to develop and test GPS-based systems in a variety of operational environments. The simulator can create static and dynamic test scenarios for vehicles moving on the ground, in the sea, and in the air, as well as space vehicles with velocities up to 30,000 meters per second.

The Lightning Detection and Ranging (LDAR) system is a network of lightning-monitoring stations developed at KSC and used daily to enhance the safety of personnel and equipment. LDAR is a unique system because it gives the locations of lightning activity in three dimensions and its coverage extends tens of kilometers beyond the KSC area. Data from the KSC LDAR system is used by the National Weather Service in Melbourne, Florida, to improve their weather forecasting in the Central Florida area. For the past 3 years, the Navigation and Landing Aids Laboratory has conducted the advanced development work for LDAR and has been the lead Government engineering group supporting the technology transfer of the system to Global Atmospherics Incorporated for commercialization.

As a follow-on to the LDAR development work, the laboratory was asked by the KSC Weather Office to design and install two new systems for the KSC and Cape Canaveral Air Station wind towers. This Mesonet Expansion will add a visibility sensor and a soil moisture content probe to selected weather monitor (Mesonet) towers. The visibility sensors will be located close to the St. Johns and Indian Rivers to give the Spaceflight Meteorology Group (SMG) in Houston, Texas, an indication of fog conditions at KSC and, thereby, reduce the risk of Shuttle landings in reduced visibility. The soil moisture sensors will permit effective initialization of the emerging generation of high-resolution numerical weather prediction models being tailored for predicting weather during spaceflight operations at KSC.

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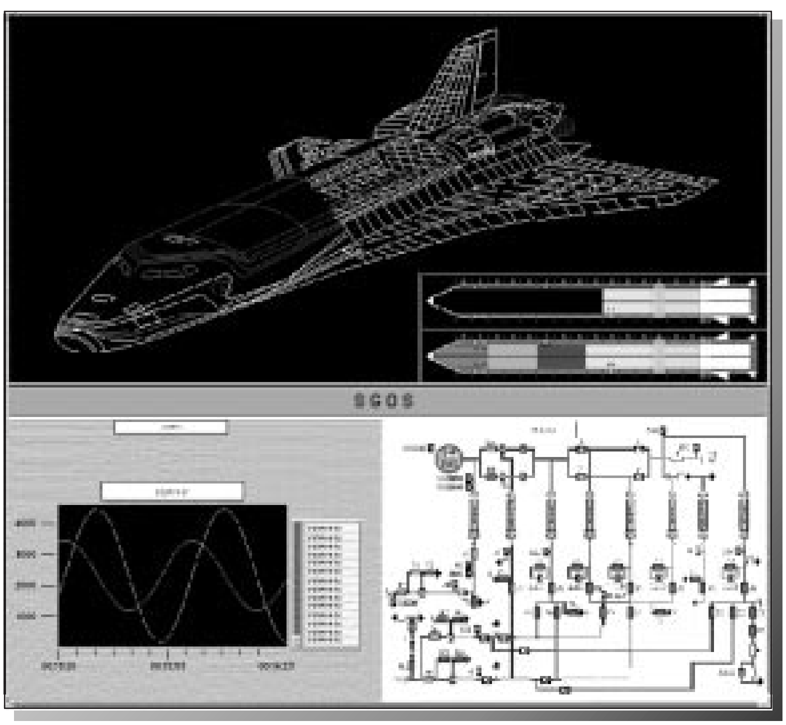
KSC Simulation System

Since the early days of the Space Shuttle program and throughout the Shuttle era, simulation at KSC has always played a vital role in ensuring launch software and launch personnel are “flight ready.” In the past, the simulation function was performed on a large mainframe computer. It was called the Shuttle Ground Operations Simulator (SGOS). The SGOS was composed of several compilers (two of which were custom inhouse products), a Fortran compiler, and a mainframe assembler. Due to increasing maintenance costs and an aging mainframe, it became necessary to replatform the simulation system. The SGOS has been replatformed from a mainframe to run on a 6U VME single-board computer and a server or on a stand-alone server.



Shuttle Ground Operations Simulator Display

In its real-time configuration, the SGOS appears to the launch firing rooms as if it were the actual Shuttle and its associated ground support systems. Using the SGOS in this manner allows the firing room software to be safely debugged while not jeopardizing the real Shuttle and other hardware and allows firing room personnel to be trained by experiencing a simulated launch countdown. During the simulation, the test team trainers may introduce random failure scenarios using the SGOS. The SGOS also allows new hardware and software design changes to be tested before implementation to observe their impact on the overall launch system.

The simulator has three modes of operation: Interactive Remote Terminal (IRT), Pseudo Real Time (PRT), and Real-Time (RT). The IRT mode allows math modelers to test and debug the actual math models themselves. The PRT mode supports the Checkout, Launch, and Control System (CLCS) desktop debug environment (DDE) for debugging firing room applications at the developers desktop. In these modes, the math models are executed on a UNIX (SUN Solaris)-based server. Up to 30 different models may be run in this mode with up to 25 users interacting with each model. Through a simple but powerful graphical user interface (GUI), users may send commands to stimulate the model and receive responses back on an X-Window terminal from their desk or almost any other location. From this X-Windows/Motif SGOS Model Control (SMC) application, users may also invoke external programs called procedures to automatically send and receive data from the model. Through these procedures, the model can be set to any desired state, which would have taken thousands of steps to accomplish manually. Users may send both normal stimuli and ad hoc failures to the model from the SMC window. Recording and tracing of model variables and execution flow can also be initiated from the SMC window.

The RT mode is run during countdown simulations. This mode retains all the

Simulation Support Servers

capability of the interactive mode, with the additional capability of communicating with the firing rooms. In this mode, the models are slowed down to operate in real time to fully emulate the real-world hardware and software. The RT mode enables model data to be sent and received via the VME bus, which is an industry standard computer bus architecture for communication between multiple processor boards. In this architecture, the model is run on a VME-based central processing unit board that communicates with other VME boards that, in turn, communicate to the firing rooms. Since the RT mode also incorporates the features of the IRT mode, model data flow and control using TCP/IP can be accomplished simultaneously with firing room data flow and control using VME. This dual channel data/control path (VME and Ethernet) is one of the more salient features of the new SGOS.

The default step size of the SGOS is 50 milliseconds with a capability of down to 5 milliseconds. Models can have up to 200,000 variables and 8,000 subsystems, yet still run in real time. This feature is made possible by using a technique called segmented execution, where only the model segments needing recalculation are executed during a model cycle.

The new system has been designed to use the original modeling language by replacing the legacy custom-written model and procedure compilers with two higher level translators, one for models and one for procedures. These translators convert the original models into “C” code, which is compiled and linked to the SGOS Executive. This solution allowed KSC to save the cost, time, and risk of having to retrain an entire department of math modelers and to rewrite more than 700 complex math models and more than 1,000 model control procedures (MCP’s). To add even more savings, this was largely accomplished using GNU products, which were free. Future plans are to add an object-oriented “building block” GUI for the construction of “codeless” math models.

VME Single Board Computer (Simulation Engine)

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Participating Organizations: NASA DP (C. Alvarado, J. Busto, J. Celsor, M. Dick, K. Grant, and N. Taylor) and United Space Alliance (C. Achee, J. Coulter, L. Graves, T. Miller, and K. Sullivan)

Payload Ground Handling Mechanism (PGHM) Automation

The PGHM is located in the Payload Changeout Rooms of Space Shuttle Launch Pads A and B at KSC. The PGHM is used to remove or insert the Shuttle payload from both the orbiter payload bay and the payload transport canister. The PGHM provides the capability to load/access payloads when the vehicle is at the launch pad. Upgrades to PGHM systems are required to provide United Space Alliance operations personnel the capability to process vertical payloads in a safer and more efficient environment. The PGHM consists of the following mechanisms:

- Power X: coarse vertical motion
- Power X Stop Nut: redundant safety feature of Power X
- Power Y: coarse side-to-side motion
- Payload Support Beam X (PLSB X): fine vertical motion
- Payload Support Beam Z (PLSB Z): fine insert and retract motion
- Stem Strain: PGHM weight distribution stability
- J-Hooks (X, Y, and Z): very fine motion

The current PGHM design uses pneumatics and manpower for axis actuation. Through automation, position feedback circuits, and elimination of hazardous manual drive systems, the proposed upgrades will provide a safer, more efficient processing environment. The project scope will be divided into two major efforts:

1. **Automated Control of Mechanisms**. The Power X, Power X Stop Nut, Power Y, Payload Support Beam X, Payload Support Beam Z, and Stem Strain mechanisms will be automated using commercial off-the-shelf electronic control systems. Numerous hardware-critical failure points and human-intervention-dependent operations will be eliminated. A centralized control console with a GUI will be provided for the PGHM move director to command operations. The main objectives are to:

   a. Eliminate the hardware single failure points.

   b. Eliminate the operations in which human error could cause hardware damage or human injury.

   c. Provide better control and feedback to the payload move director and technicians.

   d. Increase the operational efficiency and reduce the number of personnel required for payload transfer.

2. **J-Hook and Orbiter-to-Payload Position Measurement Study**. J-hook and orbiter-to-payload position measurement requirements will be detailed and the system design approach will be determined in a study.

Key accomplishments and milestones:

- 1999: Designed and built control system for Launch Pad A.
- 2000: Install system in Launch Pad A and build system for Launch Pad B.

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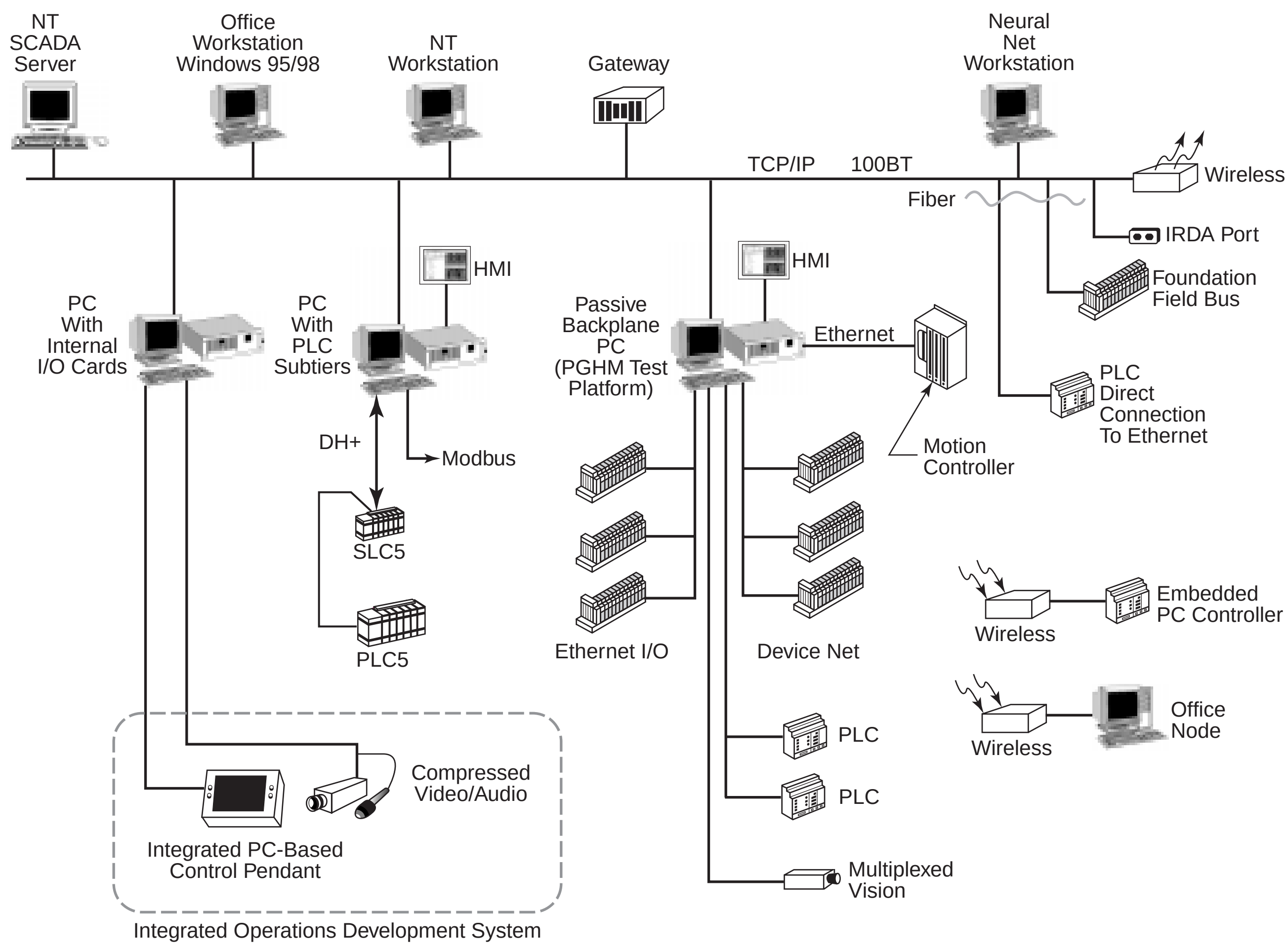
Participating Organizations: United Space Alliance and Dynacs Engineering Co., Inc.

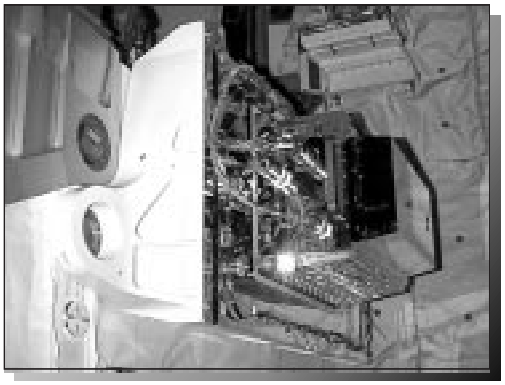


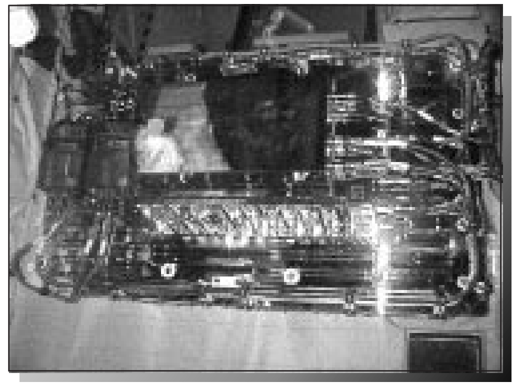
Space Shuttle Integrated Vehicle Health Management (IVHM) Flight Experiments

The IVHM Human Exploration and Development of Space (HEDS) Technology Demonstration 1 (IVHM HTD-1) system was the first of two flight experiments to be installed on Discovery, orbiter vehicle 103 (OV-103), to demonstrate new technology instrumentation. The IVHM HTD-1 was flown during STS-95 in October 1998. The IVHM HTD-2 system, also installed on OV-103, was flown during STS-96 in May 1999. Both experiments utilized hardware consisting of a Versa Module European (VME) air transportable rack (ATR) avionics box; an adapter plate; get-away special (GAS) beam; mounting hardware to mount the ATR to the adapter plate and the adapter plate to the GAS beam; orbiter power circuitry/cabling to supply 28-volt direct current power to the ATR; an interface to the orbiter timing buffer; sensors; and harness and sensor mounting hardware.

The sensors of the IVHM HTD-1 system include the following: six sensors in the orbiter aft compartment to detect gaseous hydrogen; two sensors in the orbiter aft compartment to detect gaseous oxygen; one sensor on each of the three main engines to measure temperature at the gaseous oxygen interface; one sensor at each vent of two main propulsion system helium solenoid valves in the orbiter aft compartment to measure leaks; two smart sensors to measure pressures in the cryogenic distribution system vacuum-jacketed lines; one pressure sensor to measure the positive pressure in the external tank/orbiter umbilical plate gap; two sensors to measure strains on the main engine 3 thrust structure strut; one sensor to measure the main engine 3 thrust structure strut temperature in conjunction with the strain sensors to compensate for strains introduced by thermal affects; four sensors located on the cryogenic valves for the oxygen manifold, hydrogen manifold, fuel cells reactant valves, and environmental control and life support system in the power reactant storage and distribution to measure temperature; three sensors mounted to the liquid hydrogen feed system to measure temperature on the feed system flange surfaces; and four sensors to measure the IVHM VME chassis temperatures.

The sensors of the IVHM HTD-2 system include all of the IVHM HTD-1 sensors as well as a fiber-optic sensing system developed by the Rockwell Science Center to measure strain and temperature on the main engine 3 thrust structure strut; another fiber-optic sensing system developed by Langley Research Center to measure hydrogen leaks and temperature in the aft of the orbiter near the liquid hydrogen main fuel valve and 50-1 door; eight main engine accelerometer channels spliced into the Modular Auxiliary Data System (MADS) to allow monitoring the vibration of main engine 3 in real-time using software developed by the Marshall Space Flight Center; and four wireless micro-miniature temperature recorder units installed internal to the VME chassis to monitor chassis temperatures.





IVHM HTD 1 and 2 Payload Bay Installations

Internal to the VME ATR avionics box is the necessary conduction-cooled printed circuit boards (cards) for the IVHM HTD system software to receive, process, and record the measurements from the various sensors. Both IVHM HTD-1 and HTD-2 utilized a single-board computer card, two flash storage cards, an IRIG time code reader card, an RS-485 communications card, and a custom sensor control and power distribution card. For IVHM HTD-1 only, signal conditioning and analog-to-digital conversion were provided by three data acquisition cards housed internal to the ATR. For IVHM HTD-2, the necessary signal conditioning, analog-to-digital conversion, sampling, and data acquisition of the conventional sensors were provided by remote health nodes developed by Sanders for the X-33 program.

The IVHM HTD experiments were powered on prior to cryogenic propellant loading in terminal launch countdown through ascent. After a specified mission elapsed time, the IVHM HTD's were powered down. Power to the IVHM HTD's was applied and removed daily while in orbit to allow for scheduled 1-hour snapshot periods to collect samples of sensor data. The IVHM HTD experiments were not powered on during reentry.

Prior to launch, monitoring of the IVHM HTD system was through the T-0 umbilical via an Ethernet 10BaseT physical interface connection to an HTD workstation/console in the Launch Control Complex (LCC), Room 2R24. The HTD workstation in the LCC monitored the expected time of liftoff and sent updates of this time to the IVHM HTD's. This Ethernet interface allowed the IVHM HTD to output the sensor data to the Checkout and Launch Control System (CLCS) in the Launch Control Complex area for processing and display monitoring. At approximately T-10 seconds prior to liftoff, the IVHM processor autonomously began recording data to the flash storage cards. Data recording continued during ascent and on-orbit. After landing and once the orbiter had returned to the Orbiter Processing Facility, the IVHM HTD data recorded during ascent and on-orbit was dumped to the CLCS via the Ethernet interface.

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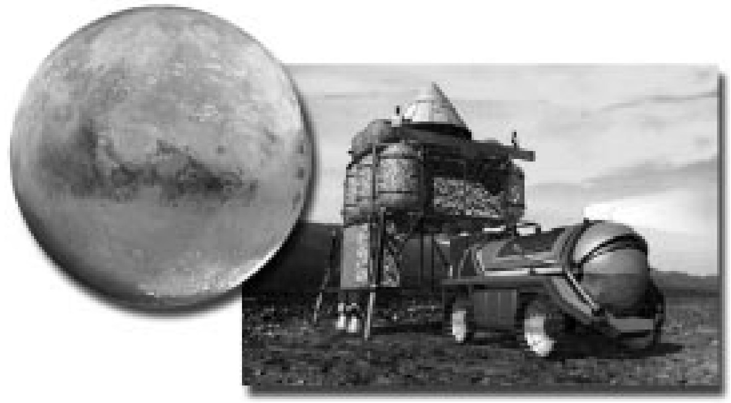
Participating Organizations: United Space Alliance; Langley Research Center; Boeing North American; Marshall Space Flight Center; Johnson Space Center; Dynacs Engineering Company, Inc.; University of Maryland; Glenn Research Center; Oklahoma State University; Lockheed Martin Sanders; Rockwell Science Center; and Hampshire Vanguard Technology Associates



Fluids and Fluid Systems

Cryogenics Testbed Facility

KSC expects its new Cryogenics Testbed to become a nationally recognized facility. The testbed is designed to be a resource that extends beyond the confines of KSC. Independent surveys conducted throughout NASA, other Government agencies, and industry have shown that the unique testing capabilities of the Cryogenics Testbed are needed.

The original Cryogenics Testbed Laboratory was expanded into a larger testbed in order to offer research and development capabilities that will benefit projects originating from KSC, academia, and private industry. The testbed is used to develop new cryogenic technologies and test cryogenic systems, components, and materials using state-of-the-art equipment.

The testbed's concept began with a partnership between NASA and Dynacs Engineering Co., Inc., KSC's engineering development contractor. Dynacs

Cryogenics Testbed Laboratory

has conducted cryogenic research for NASA, and a reimbursable Space Act Agreement gave the company authority to manage projects for industrial clients. KSC manages projects with other NASA centers and Federal customers. Once this agreement was finalized, Florida's Technological Research and Development Authority (TRDA) committed $750,000 to expand KSC's cryogenic infrastructure. The University of Florida and Air Products and Chemicals, Inc., are also partnering with KSC. Air Products' involvement focused on setting up the testbed for commercial applications, while the school focuses on computational analysis.

Potential customers exist in a wide range of scientific disciplines and commercial industries. Biological and medical researchers and doctors use liquid nitrogen for preservation and storage of cell tissue and to destroy cancer tissue through cryosurgery. Hospitals use superconductive magnets cooled in liquid helium for magnetic resonance imaging (MRI), and the food industry uses liquid nitrogen for freezing and long-term storage.

The expansion of KSC's cryogenic infrastructure will also position the Space Coast to better support the spaceports of the future, the next generation of reusable launch vehicles (RLV's), exploration missions to Mars, future space initiatives, and new business. One development project involves a partnership with Dynacs and the University of Florida to test a magnetically coupled pump that was not specifically designed for cryogenics for liquid oxygen service.

Current work at the Cryogenics Testbed, located in KSC's industrial area, includes:

- Cryogenic insulation systems development
- Cryogenic flow testing and analysis
- Conceptual design and prototype construction
- High vacuum and leak detection
- Cryogenic process system design and testing

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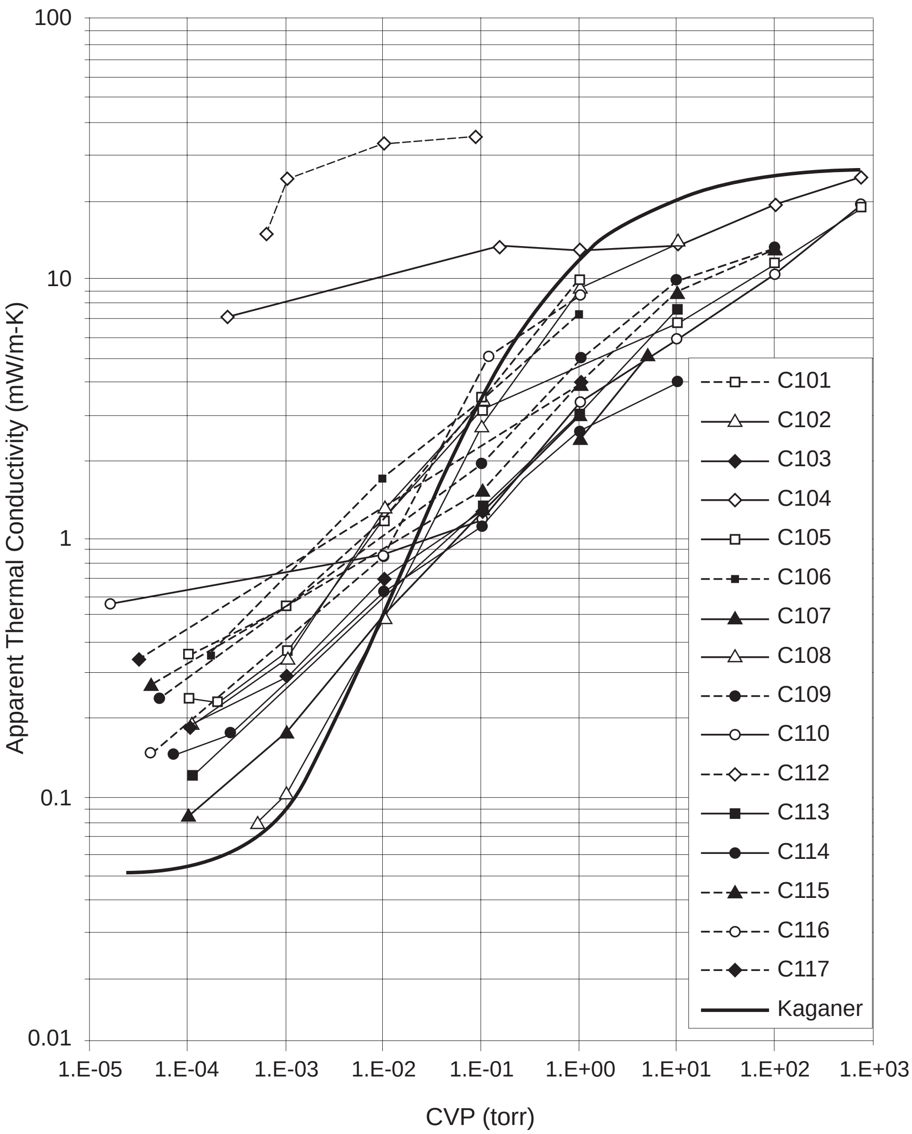
Development of Cryogenic Thermal Insulation Systems

Cryogenics is fundamentally about energy, and thermal insulation is about energy conservation. Much heat (energy) is required to produce a little cool. Thermodynamics can thus be reduced to a tradeoff between refrigeration (energy bill) and the refrigerator (capital cost). Any product losses during storage and transfer can then be directly equated to monetary losses. The technological developments of the last century have led to insulation systems that have approached the ultimate limit of performance. More technologies and markets forecast for rapid expansion into the 21st century will require, in many cases, not superinsulations but more efficient systems for a wide variety of cryogenic applications. The development of efficient, robust thermal insulation systems that operate at a soft-vacuum level is a target area of research for the Cryogenics Test Laboratory.

Low-temperature insulation can be divided into three levels of apparent thermal conductivity (k-value): around 30 milliwatts per meter-kelvin (mW/m-K) for materials at ambient pressure, about 1.5 mW/m-K for bulk fill materials at good vacuum, and below 0.1 mW/m-K for multilayer insulation (MLI) at high vacuum. [Boundary temperatures for all k-values are approximately 80 and 300 kelvin (K).] Standard MLI systems, such as those using aluminum foil and fiberglass paper spacers, represent the benchmark for comparison. MLI or superinsulation requires a vacuum level below 10^{-4} torr to be effective. Other drawbacks of MLI are that it is highly anisotropic, is sensitive to compressive loads and edge effects, requires careful attention during installation, and is limited to application on simple structures. The steps of evacuation, heating, and vacuum retention are costly and time consuming. Thermal performance degrades rapidly for vacuum levels above 10^{-3} torr. It is important to recognize that there are three levels of performance of MLI: ideal, laboratory, and actual. Actual performance is typically several times worse than the laboratory performance and can easily be 10 times worse than the ideal.



Apparent Thermal Conductivity as a Function of Cold Vacuum Pressure for Various Material Systems

The heat leak for the overall mechanical system can in turn be several times more than that estimated for the insulation system alone.

The appropriate choice of a thermal insulation system depends on matching the performance level with the overall cost. That is, the performance must justify the cost. The main factors in system design are the operating conditions, the total heat leak of the total system, material properties such as density and compatibility, and the methods of testing and evaluation. The complete economics picture for an insulation system depends upon the energy tradeoff for the system life cycle. The materials used in manufacturing a high-vacuum vessel are only a small fraction of the total cost; but the closely related steps of heating, vacuum pumping, testing, and handling are quite costly. In summary, the overall effectiveness of the system of insulation depends on: (1) thermal performance, (2) versatility and durability, (3) ease of use in manufacturing and installation, and (4) costs of operations and maintenance. Today's choice is generally between a k-value of ~0.1 mW/m-K (R1440) or ~30 mW/m-K (R4.8). Many applications call for an intermediate level of thermal performance or perhaps a lower performance with longer life. When examining a system design from a total energy standpoint, superinsulation may be excessive. A great potential for improvement in the applications area is the offering of "soft vacuum" (1- to 10-torr range) insulation systems at low cost with performance several times better than conventional foam systems. Whether it is an affordable piping system or new advanced containers, the present opportunity is to bridge the gap between R5 and R1500 in terms of both cost and performance. A soft vacuum system with R30 or better performance has numerous advantages. The ability to commercialize an insulated product at vacuum levels near those produced by high-volume vacuum packaging equipment presents tremendous potential for cost-competitive, high-efficiency products.

The main goal was to develop a new soft vacuum system (1 to 10 torr) that provides an intermediate level of performance (k-value below 4.8 mW/m-K). Liquid nitrogen (LN_2) boiloff methods were used to test conventional materials, novel materials, and certain combinations. The test articles included combinations of aluminum foil, fiberglass paper, polyester fabric, silica aerogel composite blanket, fumed silica, silica aerogel powder, and syntactic foam. A total of 142 tests of 17 different insulation systems was performed using the cryostat method. The k-values at different vacuum levels are given in the figure. A total of 59 tests was performed using the dewar method. Different insulation systems inside the 10-liter-size dewars were tested after different preparations of vacuum pumping and heating.

Two test methods are needed to adequately describe the overall thermal performance of an insulation system. The cryostat method provides the apparent thermal conductivity values for the material combination while the dewar method gives the actual performance for the mechanical system. A new layered composite is being developed into a family of cryogenic insulation systems. The performance level for LN_2 and 1-torr conditions was measured to be 2.4 mW/m-K (R60). This system is targeted for low-cost, intermediate performance uses but also offers advantages for high-vacuum superinsulation applications. Performance at LN_2 and 10^{-4} torr conditions was 0.09 mW/m-K, which is near the benchmark MLI. The actual performance of the more robust composite could exceed that of the highly evacuated MLI when the factors of edge effects and compression are considered. The "vacuum burden" of fabricating 1-torr systems versus 0.0001-torr systems is accordingly reduced. The layered composite insulation should benefit industry for the storage, transfer, or handling of low-temperature fluids by lowering the manufacturing and life-cycle costs for equipment. These insulation systems should also allow for more flexibility in the overall design and implementation of cryogenic systems, a key benefit to the cryogenic equipment on Earth and in space.

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Participating Organization: Dynacs Engineering Co., Inc. (S.D. Augustynowicz)

Testing Technologies for Cryogenic Thermal Insulation Systems

A core line of work at the Cryogenics Test Laboratory is the development of thermal insulation systems. The objective of this line of work is to develop the materials, testing technologies, and engineering for the efficient storage, transfer, and use of cryogens and cryogenic propellants on Earth and in space. The testing technologies include design, testing, evaluation, and performance measurements for a wide range of materials and systems from 77 kelvin (K) to 350 K and from 760 torr to a 10^{-6} torr vacuum level.

Figure 1. Guarded Insulation Test Apparatus (Cryostat-1)

These capabilities are described as follows.

Cryostat-1 - The cryostat test apparatus shown in figure 1 is a liquid nitrogen boiloff calorimeter system for direct measurement of the apparent thermal conductivity at a fixed vacuum level. The system is a cylindrical, liquid nitrogen guarded configuration. Continuously rolled materials are installed around a cylindrical copper sleeve (or cold mass) using a 1-m-wide wrapping machine. The sleeve is slid onto the vertical cold mass of the cryostat. Sensors are placed between layers of the insulation to obtain temperature-thickness profiles. The temperatures of the cold mass (maintained at 77.8 K), the sleeve [cold boundary temperature (CBT)], the insulation outer surface [warm boundary temperature (WBT)], and the vacuum chamber (maintained at 313 K by thermal shroud) are measured. The measurable heat gain rate for this apparatus is from 0.2 to 20 watts; the surface area for a typical 25-mm-thick insulation test article is 0.63 m^2. The steady-state measurement of k-value is made when the vacuum level, all temperatures, and the boiloff flow are stable.

Cryostat-2 - The cryostat test apparatus shown in figure 2 is a liquid nitrogen boiloff calorimeter system for calibrated measurement of the apparent thermal conductivity at a fixed vacuum level. The system is a cylindrical, aerogel insulation-guarded configuration. Continuously rolled materials are applied directly to the removable cold mass using a 0.5-m-wide wrapping machine. This system allows a high rate of testing different samples and can also be configured for flat-plate geometries. The sleeve is slid onto the vertical cold mass of the cryostat. Sensors and measurements are similar to that of cryostat-1. The measurable heat gain rate for this apparatus is from 0.7 to 40 watts; the surface area for a typical 25-mm-thick insulation test article is 0.26 m^2.

Dewar Test - The dewar test apparatus provides a means of determining the "real-world" performance of an insulation system, with consideration given to the fabrication, quality control, testing,

Figure 2. Calibrated Insulation Test Apparatus (Cryostat-2)

and operation of the cryogenic tank. This method gives a direct measure of actual system performance as a function of cold vacuum pressure (CVP). The dewars are typically 10-liter vacuum-jacketed aluminum vessels. A custom-built 0.5-m-wide wrapping machine is used for installing continuously rolled materials onto the inner vessel. A vacuum pumping station with a shutoff valve and bake-out system are connected during test preparations. Capacitance manometers connected to the vacuum port are used for measuring vacuum levels from $5x10^{-5}$ to 100 torr. A transfer standard mass flowmeter with a thermal conditioning coil is connected to the dewar. The entire setup is mounted on a precision weight scale for the primary test measurement. The ambient conditions (temperature, barometric pressure, and humidity) must also be monitored. The weight loss due to the boiloff of nitrogen gas is proportional to the total heat leak into the inner vessel.

Pipeline Test Apparatus – The pipeline test apparatus is designed for precision thermal performance measurements of pipeline systems. The pipelines may be rigid or flexible in lengths up to 60 feet. Three pipelines with outside diameters of up to 8 inches may be installed at one time. Both ends are thermally guarded by liquid nitrogen reservoirs with special mounting adapters. Test article surfaces are maintained at a constant warm temperature of about 310 K using a heater jacket. Static nitrogen boiloff flow rates are recorded after a suitable stabilization period.

Milestones:

- 2000: Installation of a complete property measurement and data acquisition system.
- Adapt the system to use for other process fluids under dynamic (flow-through) conditions.

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Participating Organization: Dynacs Engineering Co., Inc. (S.D. Augustynowicz)

Long-Term Storage of Cryogens on Mars Using a Soft Vacuum Thermal Insulation System

Missions to explore Mars will require complex, autonomous systems that are highly energy efficient, integrated across all subsystems, and robust. The long-term storage of cryogens, in particular liquid oxygen and liquid methane, is an important challenge for the planned step-by-step success of these missions. Liquid oxygen supplies for life support and for return trips to Earth will be produced well in advance of the human missions and must remain ready to use for a variety of contingency scenarios. The atmosphere on Mars — in regard to the concerns of thermal insulation — is between that of Earth and that of outer space. Earth is "no vacuum," space is "high vacuum," and Mars is "soft vacuum" (about 5 torr or 7 millibars), composed primarily of carbon dioxide. Mars' ambient temperature is in the range of a cool, but not cryogenic, -100 degrees Fahrenheit (200 kelvin).

Work at the Cryogenics Test Laboratory has focused on the first step in the design of suitable insulation systems, which is to test and evaluate the thermal performance of different materials in the approximate Martian environment. The performance levels have been found to have large variations in the soft vacuum region as indicated by the figure. This region is very dynamic because radiation, gas conduction, and convection (as well as solid conduction) are all significant contributors to the total heat leak into the inner vessel. Tests are typically conducted in nitrogen (for comparison), in carbon dioxide, and in high vacuum as well. Performance variations between nitrogen and carbon dioxide environments at a 5-torr vacuum level have been seen for certain types of composite materials.

Milestones:

- 2000: Completion of a dedicated cryostat (Cryostat-3) for the testing of candidate materials. The two best material systems will be selected based on thermal performance, bulk density, outgassing, durability, and mechanical factors.
- 2001: Design and fabrication of a tank prototype using the optimized thermal insulation system.

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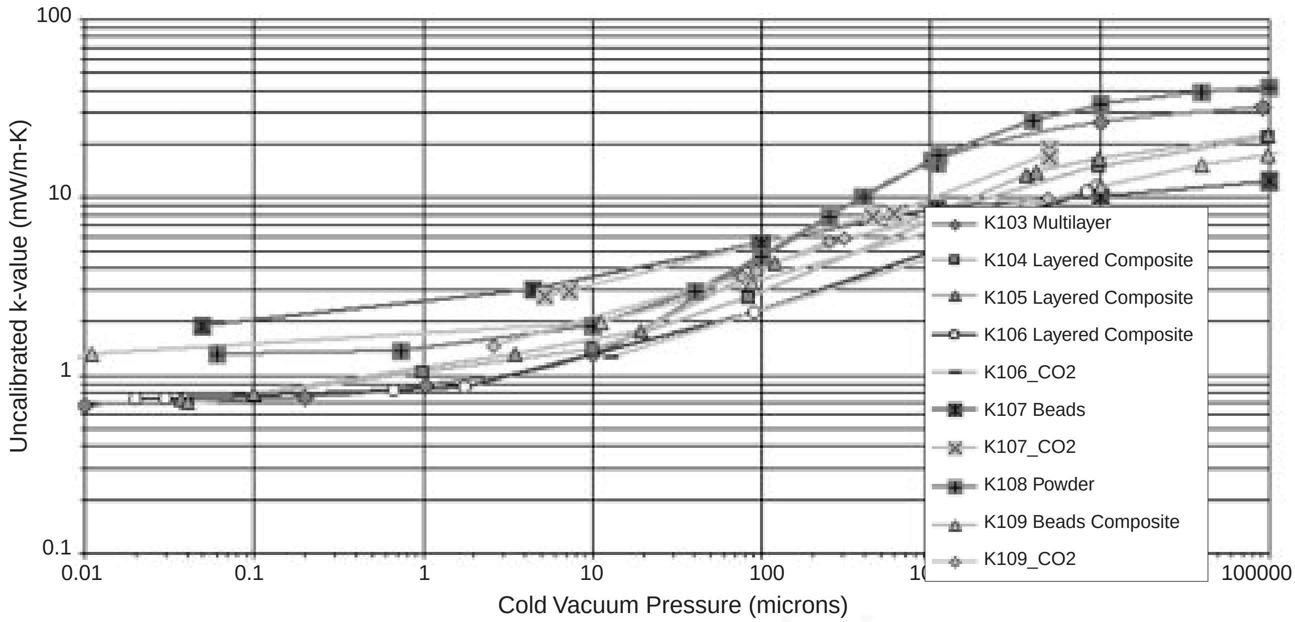
Participating Organization: Dynacs Engineering Co., Inc. (S.D. Augustynowicz)



Thermal Performance as a Function of Cold Vacuum Pressure
Cryostat-2 Insulation Test Summary

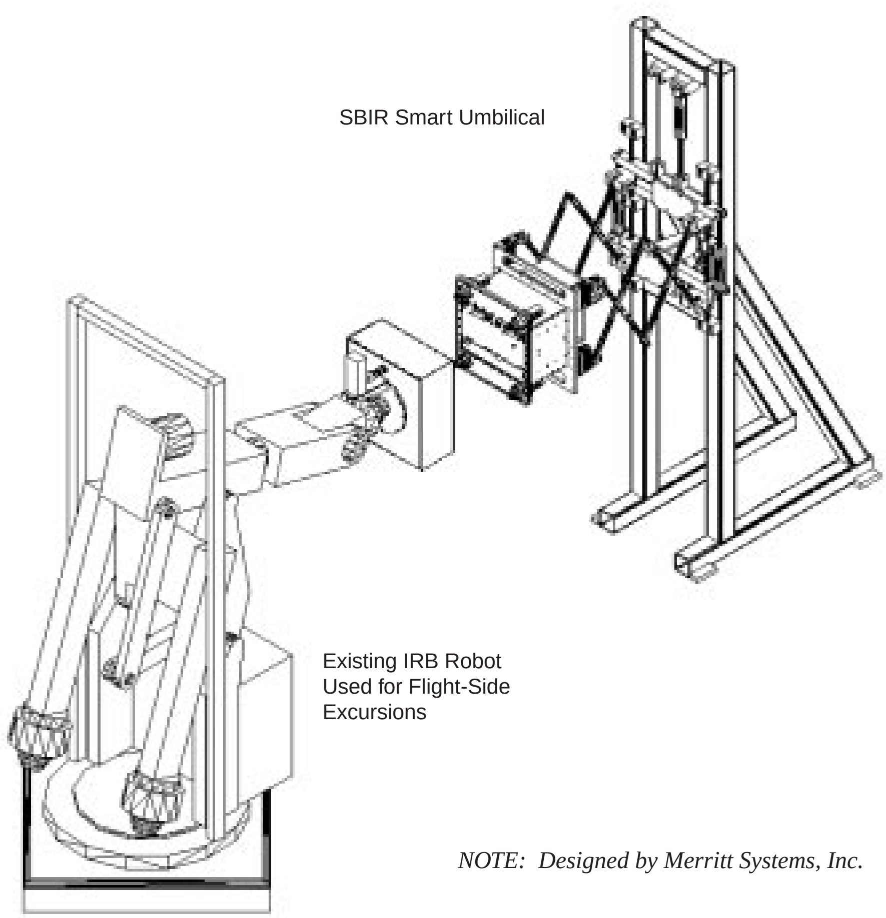
Automated Umbilical Mating Technology

Numerous launch vehicles, planetary systems, and rovers require umbilical mating for fluid flow and electrical connections. Simple, reliable, autonomous mating is required to make certain missions and systems feasible (i.e., Mars methane-fueled rovers) and to provide low-cost, safe launch operations. The environment for mating (temperature, humidity, dust, cost, weight, and power) varies drastically from system to system. However, a common core technology and numerous sensor and mating techniques are needed to provide low-cost, common solutions for all systems. The technical approach involves the following:

- Development of a smart umbilical with a reconnect capability. [This project will leverage off an existing Small Business Innovation Research (SBIR) project and additional available hardware.]
- Autonomous or remote operations using vision systems, force feedback, miniaturized gas detection, and real-time control.
- An umbilical that provides the capability to connect, disconnect, and reconnect during any point in the launch countdown process.
- Investigation of various sensor and mechanism concepts for different mating environments.

The benefits to NASA missions involve the following:

- Autonomous methane-fueled Mars exploration rovers (required for Mars sample return).
- Capability to connect, disconnect, and reconnect during any point in the countdown process for the Reuseable Launch Vehicle (RLV), Liquid Flyback Booster (LFBB), and Evolved Expendable Launch Vehicle (EELV). Low-cost, high-reliability autonomous mating will enhance all future launch vehicles.
- Cost-effective, safer launch operations
- Enhanced launch reliability



NOTE: Designed by Merritt Systems, Inc.

The Phase II SBIR project is complete and the project hardware is being tested to increase reliability and effectiveness. At the same time, a Phase III SBIR has been initiated and is scoped for a 3-year period. At the end of this period, the SBIR contract will have designed, built, and tested a qualifiable automated umbilical that will then be tested in the Launch Equipment Test Facility (LETF) area under cryogenic and launch conditions. NASA is designing the compliant carrier plate that will attach to the automated umbilical.

The Phase II SBIR hardware being tested in the Automated System Ground Support Laboratory has two fluid connections and four electrical connections. The operator manually drives the umbilical to within its alignment area, the vision control system then takes over and drives the umbilical to mate with the flight-side plate. The operator has the option to give the final permission to perform each step in the mating process and can interrupt the mating process at any time. When the mating process is interrupted, the umbilical returns to the previous safe step in the mating process or returns to the home position, depending on how it is interrupted. After the umbilical plate has been connected and latched to the flight-side plate, the umbilical system goes into a passive mode, whereby it follows the excursions of the flight side. The electrical and fluid connections are then verified for leaks and connectivity.

The operators will access system controls through the software loaded into the control console computer. From this console, the operator will have control of and feedback from the entire system as well as the camera view of the vision system. All data acquisition hardware is also interfaced to this industrial computer. Additional design requirements include compliant self-aligning ground-side carrier plate, traceability to a nonsingle point-of-failure design, real-world dynamic and static vehicle excursions, quick and reliable remote verification of interface integrity, and an IRB 90 robotic arm to mimic vehicle excursions.

Key accomplishments and milestones:

- June 1998: Completion of the SBIR mechanical design.
- October 1998: Completion of the SBIR electrical design.
- 1999: Completion of the SBIR automated umbilical.
- 2000: Modify the Phase II SBIR hardware for increased reliability and functionality; proceed with the design of a qualifiable automated umbilical.
- 2001: Build a qualifiable automated umbilical.

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Participating Organizations: Merritt Systems, Inc.; Dynacs Engineering, Co., Inc.; and Boeing

OmniBot Mobile Base

The objective of the OmniBot project is to develop a hazardous duty mobile base as an advanced development testbed to research alternate technical approaches for remotely controlled operations in hazardous areas. In addition, this base will be used to test various automated umbilical technologies for autonomous mobile vehicles. In hazardous environments where it is too dangerous to send in unprotected personnel, a mobile base could be used to perform remote inspections, site surveys, and operations.

The OmniBot is driven with four brushless servomotors connected to omnidirectional wheels (Mechanum). This allows complete 2-degree-of-freedom motion resulting in extremely high maneuverability. The benefit of this motion profile can truly be appreciated when the vehicle is operated in a teleoperational mode.

Currently, the vehicle can be controlled with a radio frequency (RF) control box or with a hardwired joystick. With the video transmission gear installed, teleoperation is possible up to a distance of 1,800 feet.

The next phase in the project is the construction of an operator’s control station, a sensor package, and manipulator systems. The OmniBot has been selected to be the motion platform for the Mars Umbilical Technology Demonstrator (MUTD) project. Modifications were required to support the installation of the 3-axis positioning system and its associated hardware and to incorporate the software into the on-board computer.

Key accomplishments and milestones:

- January 1997: Construction of the motion base.
- June 1997: Testing of the motion base and control system.
- March 1998: Construction of the RF control system.
- August 1998: Selection/procurement of the multitasking system.
- September 1998: Installation of the video RF gear.
- 1999: Modification to the motion base for the MUTD.

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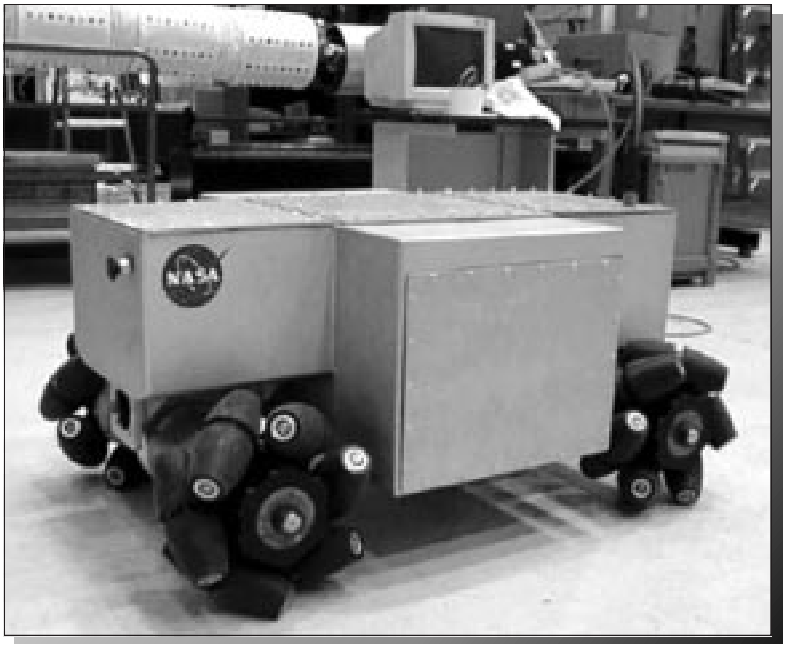

OmniBot Mobile Base

Closeup of Omni (Mechanum) Wheels

Mars Umbilical Technology Demonstrator (MUTD)

NASA is working to enable technologies to support a future manned space flight program to Mars. Because of the harsh environment, great distance away, and communication lag, autonomous mobile robots will be required to perform critical tasks on Mars. It is envisioned that a remote electrical power system will be in place prior to arrival of the astronauts, and an autonomous mobile robot will be required to connect power to the various modules as they arrive on Mars. This project will demonstrate the use of a mobile robot to deploy a power cable and connect that cable remotely to a simulated power system.

The objectives of this project are to:

- Demonstrate that a mobile robot can deploy a power cable a distance of 100 meters, locate the simulated power source, and remotely connect the power umbilical.
- Simulate two Mars vehicles. [The Cargo/Hab vehicle and the In Situ Propellant Production (ISPP) power plant will be 100 meters apart.]
- Deploy 100 meters of electrical cable from the simulated Hab vehicle to the simulated ISPP power plant.
- Align the two simulated umbilical plates and mate the connectors in an accurate and timely manner.

The MUTD deployment and connector mate will utilize teleoperation for the initial local phase and autonomous operation for the final umbilical mating procedure. No manual assist will be allowed during the deployment and mating operations. A laser system will be used for visual cues during the teleoperation phase, and ultrasonic sensors will be utilized for plate alignment. Another design feature is the 6-degree-of-freedom compliant mechanism for final alignment.

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Participating Organizations: NASA KSC Engineering Development, NASA JSC Engineering Development, and Dynacs Engineering Co., Inc.

Electro-Mechanical Actuator

The objective of the Electro-Mechanical Actuator (EMA) project is to evaluate and demonstrate the viability of electro-mechanical actuators to replace pneumatic actuation for use in launch processing ground support equipment at KSC. The current pneumatic actuation systems, such as the cryogenic fuel and oxidizer systems, firex systems, sound suppression system, etc., require high maintenance and the components are becoming old and obsolete. These systems are located at the launch pads and are exposed to the rigors of launch and the high humidity and salty seaside environment. Use of EMA's has the potential to reduce the complexity and number of components required by as much as 80 percent. Commericial off-the-shelf electro-mechanical actuators are being evaluated, and methods of providing high reliability through redundancy are being addressed. Higher position accuracy and repeatability are also potential benefits from the use of EMA's.

The EMA system consists of one electro-mechanical actuator controlled by two programmable logic controllers (PLC's) and two servodrives in a parallel configuration for highly reliable operation. Commercial use of single-string control using PLC's and servodrives for EMA's has proven these system components to be highly reliable, accurate, and economical. Once studied and proven for dual-control redundancy, the concept could provide the same benefits for critical systems.

Key accomplishments and milestones:

- April 1998: Design and layout of the EMA test plan.
- June 1998: Procurement and mounting of Allen Bradley PLC's and servodrives.
- September 1998: Procurement of Class I, Division I, electro-mechanical actuators manufactured by Exlar Corporation.
- December 1999: Procurement of Allen Bradley switches and contactor for dual-control redundancy.
- February 2000: Testing and evaluation of EMA configurations, operating characteristics, and reliability and repeatability.

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Participating Organizations: NASA Process Engineering Directorate and United Space Alliance

Low-Cost High-Efficiency Pipelines for Long-Distance Transfer of Cryogens

Thriving spaceports of the future will rely on new approaches to the supply of the requisite propellants and gases. Services built around thermally efficient, integrated launch pads supplied by centralized plants for both energy conversion and cryogenic production are envisioned. A key part of these privatized, customer-driven services will be the transfer pipelines to deliver the cryogenic fluids across long distances. Fluids common to most launch sites include helium, hydrogen, nitrogen, and oxygen. Another common feature is the intermittent operation of most of the corresponding fluid handling systems. Achieving the goal of an "energy integrated" launch site can be done if all elements are given due economic consideration at the start of the design concept.

Work at the Cryogenics Test Laboratory includes the development of low-cost high-efficiency pipelines for the long-distance transfer of cryogens. A commercial off-the-shelf vacuum-jacketed pipeline (60-foot length) with multilayer insulation and two standard bayonet joints has been mounted on the Pipeline Test Apparatus for system activation and calibration purposes. A view of this cryogenic pipeline is shown in the figure. The heat leak of this pipeline, which will be determined through a series of liquid nitrogen boiloff tests, will also serve as a benchmark for thermal performance comparison with other pipelines.

Milestones:

- 2000: Fabrication and test of a similar size pipeline with experimental insulation materials.
- 2001: Testing of custom-built pipelines and vendor pipelines under both static and dynamic flow conditions.

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Participating Organization: Dynacs Engineering Co., Inc. (S.D. Augustynowicz)

Pipeline Test Apparatus for Measurement of Thermal Performance

Mars In Situ Resource Utilization (ISRU) Testbed

The current plans for a manned mission to Mars include the use of resources available on Mars to produce fuel and oxidizer for the return trip and oxygen for breathing while on the surface. One of the preliminary projects is to build a small production facility to run automatically on Mars and demonstrate the technology prior to launching a manned mission. NASA at KSC is developing software to control the In Situ Propellant Production (ISPP) plant using a language developed at Ames Research Center. In support of the software development, KSC is also building an operating laboratory-scale production system to serve as a testbed (the ISRU Testbed) for evaluating the control software.

The ISRU Testbed is a laboratory-scale plant to produce water and oxygen using hydrogen (H_2) and carbon dioxide (CO_2) as raw materials. On Mars, the CO_2 would come from the Martian atmosphere and the hydrogen would have to be carried to Mars from Earth. Because the hydrogen is available in limited quantity, the process would use electrolysis to produce oxygen and hydrogen from the water. Oxygen is a useful product and the system would recycle hydrogen to produce more water.

The basic reaction in the ISRU Testbed is a well known industrial process called the reverse water gas shift (RWGS) reaction. The RWGS reacts hydrogen and CO_2 on a catalyst at high temperature to produce water and carbon monoxide (CO).

The CO is a waste product that is vented into a fume hood. The water is separated by the electrolyzer into oxygen, which is the useful product, and hydrogen, which is recycled into the RWGS reactor to produce more water. In this way, a fixed amount of hydrogen carried to Mars may produce many more times its weight in oxygen for breathing and for the trip back to Earth.

In the ISRU Testbed, all of the process variables (temperatures, pressures, flows, and gas composition) are instrumented electronically so that the process can be controlled by the autonomous controller software. Process variables can be changed, and failure modes can be simulated to study the normal and abnormal operation of the ISRU process. In addition, the RWGS process for oxygen production can be characterized and optimized for efficiency. On Mars, the power to operate the ISPP plant will come from solar panels; therefore, efficiency and light weight will become important considerations in building a flightworthy ISPP plant.

Key accomplishment:

- Design of the ISRU Testbed is about 90 percent complete. Construction is 10 percent complete.

Key milestone:

- March 2000: Initial operation of the ISRU Testbed.

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Participating Organizations: Dynacs Engineering Co, Inc. (C.B. Mattson, J.D. Taylor, C.H. Goodrich, and T.R. Hodge) and Pioneer Astronautics (B. Frankie)

Solenoid Valve Status Indicator

Researchers have tried to use the current signature of a solenoid valve to characterize its health. The purpose of this technology is not to determine valve health but to determine if there is correct poppet movement in the valve when the current is applied or removed. Research has identified four points of interest on the valve current waveform: (1) the valve enters a transient state, (2) the poppet begins moving, (3) the poppet completes the movement, and (4) the valve enters a steady state. Developments in digital signal processing algorithms enable a computer to automatically identify these four points and provide an indication of the solenoid valve status (energizing, energized, deenergizing, deenergized, current high but failed to energize, current low but failed to deenergize, etc.). The computer can also record and report information such as energizing time, discharging time, time the valve remained energized, and time the valve remained deenergized.

A current-sensing device (inline resistor, coil, and Hall effect sensor) is used to measure the valve current. The output of the sensor is conditioned (amplified and filtered) and then fed into an analog-to-digital converter. Once in the computer, a variety of algorithms can be applied to the signal depending on what information is required. The signal can be compared with specified thresholds to determine if the current is applied or removed. A minimum/maximum comparator filter can be used to determine the precise time and amplitude at which the poppet begins to move and completes the movement. Threshold and minimum/maximum filtering are computationally efficient straightforward algorithms that can run on inexpensive digital signal processors or microcontrollers. The computer examines the results of the filters and reports the valve is operating correctly or incorrectly. The exact reason for failure (such as jammed valve, too much friction, burned or shorted solenoid coils, weakening spring, high or low temperature, or incorrect voltage) is not reported.

Any given solenoid valve has a remarkably stable current signature when the valve is healthy. However, many things affect the exact shape of the current: solenoid inductance, number of turns in the solenoid, internal resistance of the solenoid, physical size of the solenoid, temperature of the solenoid or sensor, spring strength, friction in the poppet's path, power supply voltage and current, diodes in the circuit, pressure of the fluid in the valve, etc. During a typical operation, most of those variables are fixed for a healthy valve. Since the current signature is stable, the exact time and amplitude of the four points can be bracketed. Values within the brackets are reported as a pass, while values outside the brackets are reported as a fail. The size of the brackets can be determined manually or automatically by the computer using the standard deviation of data collected from a known-good valve. The brackets will need to be determined for each individual valve.

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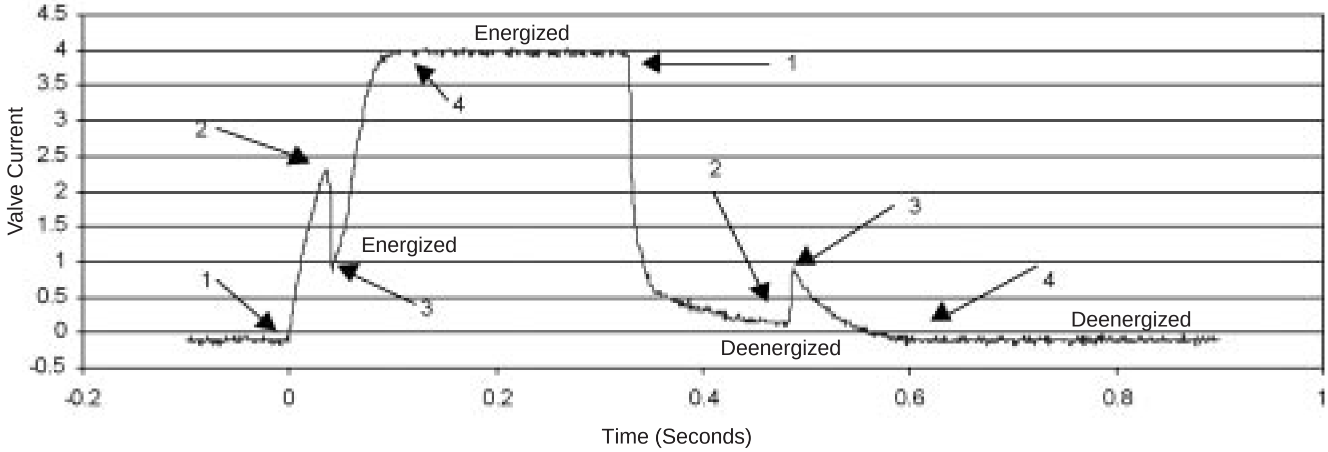
Participating Organization: Dynacs Engineering Co., Inc. (B.M. Burns)



Recorded Current Signatures of a Known-Good Valve

Evolved Expendable Launch Vehicle (EELV) Hydrogen Entrapment Test Program

The Boeing EELV launch site located on Space Launch Complex 37 (SLC-37) features an enclosed launch duct that was specifically designed to mitigate acoustic noise levels during liftoff. The enclosed duct design presents a potential hazard concerning unburned hydrogen becoming trapped in the duct. Prior to engine start and after engine shutdown during an abort on the launch pad, the EELV's RS-68 engines introduce large quantities of hydrogen into the launch duct. This hydrogen could potentially mix with air, forming a flammable or detonable mixture that could result in destructive overpressures. One proposed method for mitigating this potential hazard is to ignite the hydrogen as it enters the launch duct and keep it burning so no destructive overpressures result. Boeing requested KSC to conduct a test program to evaluate the current duct design using hydrogen/compressed air torches as an ignition source. The program included design, construction, and testing of a 1/7-scale model of the SLC-37 EELV launch duct.

The test program had three major objectives. The first objective was to determine the air entrainment characteristics of the engine exhaust plume in the duct. The second objective of the test was to determine whether or not a hydrogen/air torch can safely ignite the hydrogen in the exhaust plume and to determine if the placement of the torches relative to the nozzle exit plane was a significant factor. The third objective was to demonstrate that destructive overpressures would not occur when simulating startup and shutdown transients. To achieve the test objectives, the test program was divided into three phases: air entrainment characterization, torch placement determination, and startup/shutdown transient simulations.

During the first phase of tests (a series of air entrainment characterizations), the ratio of air entrained to nitrogen mass flow rate was determined to be 2.9 to 3.0. For the torch placement determination phase, six tests were run and the hydrogen plume was successfully ignited each time without destructive overpressures. Ignition of the plume was not sensitive to the torch position. During the startup/shutdown transient simulation phase, six 2-second abort tests and six 4-second abort tests were conducted. The hydrogen plume was ignited successfully each time with no destructive overpressures. Recommendations included testing solid propellant pyrotechnic devices as an alternate ignition source; testing a heavy vehicle, three-engine configuration; and developing a computational fluid dynamics model to better predict full-scale behavior.

Key accomplishment:

- Constructed and successfully tested a scale model exhaust system that met all three objectives.

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1/7-Scale Model of the EELV Launch Duct

X-33 T-0 Umbilical System Testing

The X-33 technology demonstrator is a key part of NASA's Space Transportation Enterprise. The X-33 is a half-scale prototype of a reusable launch vehicle (RLV) called the "VentureStar." The X-33 will launch from Haystack Butte at Edwards Air Force Base in California and land at one of two test sites. The vehicle is processed horizontally within a translating shelter, rotated to the vertical position, and then launched. As with any vehicle, the X-33 needs fuel to be able to fly. For the X-33, that fuel is supplied to the vehicle via a complex system of panels, valves, and hoses, known as the umbilicals. For the X-33 vehicle there are two primary umbilicals, the liquid hydrogen (LH_2) and liquid oxygen (LO_2) umbilicals.

Testing of the X-33 LH_2 and LO_2 T-0 umbilicals was performed at the Launch Equipment Test Facility (LETF) at KSC from April 21, 1999, until July 7, 1999.

Test objectives accomplished:

- Verified the structural integrity of the system components.
- Obtained actual physical data measurements for comparison with the design criteria and dynamic models.
- Validated the hardware operation under nominal and off-nominal umbilical release configurations.
- Verified the operation of all mechanical subsystems.
- Verified the synchronization of operational sequences of all moving components.
- Verified the intended function of the components and subsystems.
- Developed the operating sequences and procedures.
- Provided familiarity of the operations associated with the X-33 T-0 umbilical system for operations personnel.

The X-33 LH_2 and LO_2 T-0 umbilicals were successfully verification tested. Proper ground T-0 (GT0) panel separation from the vehicle T-0 (VT0) panel was demonstrated. Timely operation of the translating frame, blast doors, and flight doors was also exhibited.

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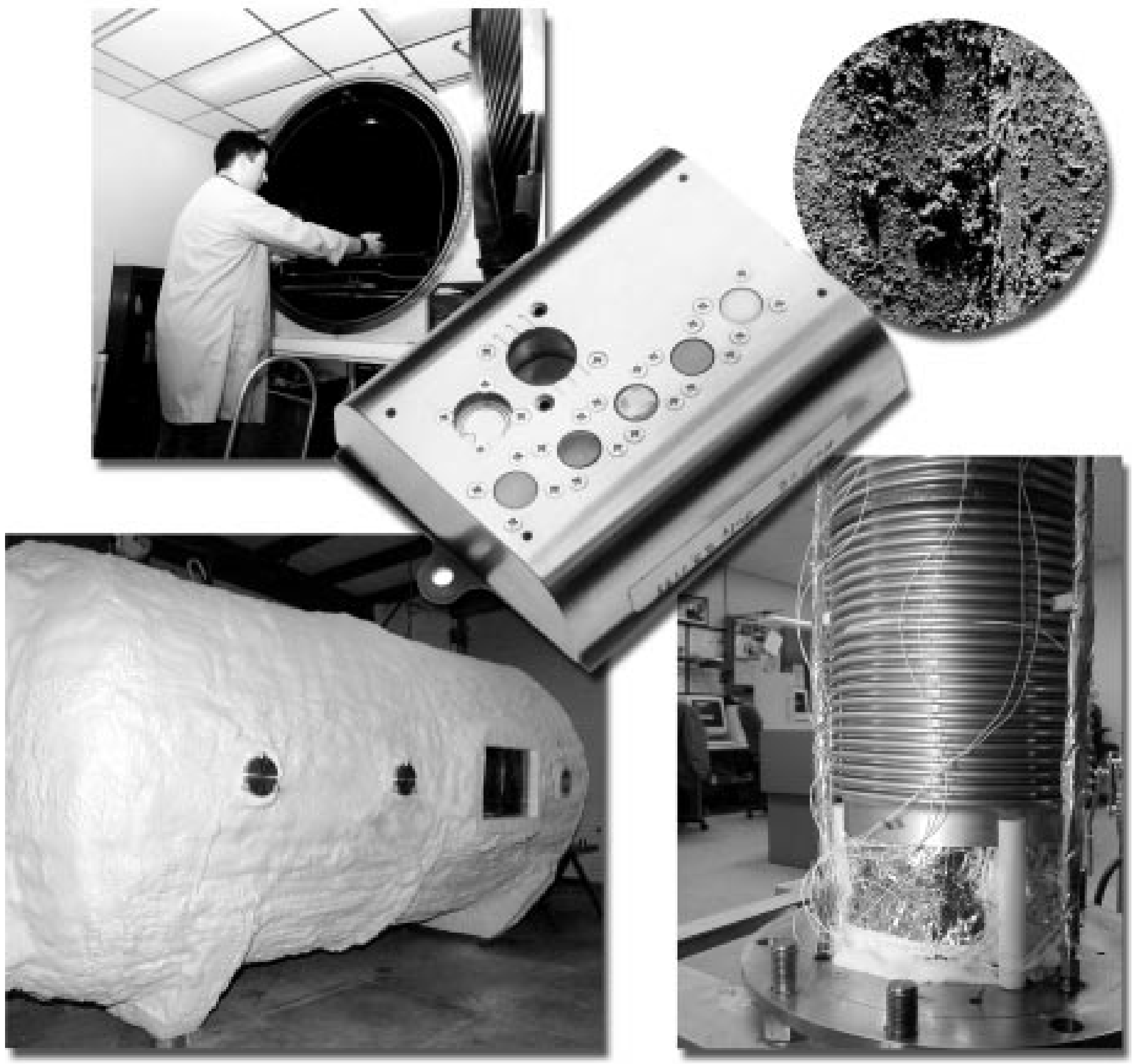
Umbilical for the X-33 Technology Demonstrator

Materials Evaluation



KSC Materials Science Division

For three decades, KSC's Materials Science Division (MSD) has supported KSC, Cape Canaveral Air Station (CCAS), other NASA centers, Government agencies, and aerospace contractors in the development and evaluation of materials and processes associated with flight hardware and ground support equipment.

The MSD is composed of the Test Division and the Analysis Division. The functions of the MSD are to identify any material in any quantity and determine the cause of any failure. In addition, laboratory personnel serve as consultants for materials-related Technology Transfer Agreements and Small Business Innovation Research (SBIR) projects.

The MSD, part of the Logistics Operations Directorate, has over $8 million in high-technology state-of-the-art equipment and instrumentation contained in 24,000 square feet of space in the Operations and Checkout Building. The MSD is currently staffed with 42 Civil Service scientists, engineers, and technicians who are highly educated, experienced, and nationally recognized and networked in their fields of expertise. Areas of expertise include chemistry, physics, materials science and engineering, metallurgical engineering, welding engineering, corrosion engineering, chemical engineering, metrology, mechanical engineering, and electrical engineering.

The MSD was established to provide rapid material and process engineering and failure analysis support to vehicle and institutional operations. Today, the laboratory's responsibilities include institutional, Shuttle/payloads, and technical community support involving: failure analysis; chemical analysis; material and process selection, testing, and evaluation; materials compatibility testing; material and process specifications and standards development; and applied research.

Currently, NASA's Planet Mars program generates considerable work for the MSD. The laboratory is working on three Mars environmental chambers. The largest chamber is 17 feet long and 7.5 feet in diameter with a 4-foot-by-4-foot access door. The intended use of the chamber is to test the long-duration reliability of the In Situ Resource Utilization (ISRU) hardware to be used on the Martian surface, although other Martian hardware may also be tested. The purpose of the ISRU is to produce oxygen and possibly a fuel utilizing the Martian atmosphere (mostly carbon dioxide). Utilization of planetary resources reduces the necessity of carrying those consumables from Earth.

When completed, the large Mars chamber will be capable of simulating the Martian surface in all aspects except reduced gravity. The chamber will control the atmospheric composition and temperature (95 percent carbon dioxide at 5 to 11 torr and –150 to 30 ^{o}F). Lighting will be installed to simulate the solar irradience and a system of chiller tubes using circulating liquid nitrogen and heater strips will be able to imitate the diurnal solar cycle. The use of a Martian soil simulant and a wind generator to imitate Martian dust storms is also being considered. The chamber, which has been partially tested with a vacuum down to 500 millitorr and a carbon dioxide atmosphere at 7 torr, is currently being fitted with five banks of liquid nitrogen cooling coils. Upon completion, the chamber will be pumped down and the cooling system operation will be checked.

A midsize Mars chamber, 4 feet long and 3 feet in diameter, is currently nearing completion. This chamber will provide the atmosphere and temperature simulation of the Mars surface for the purpose of testing material electrostatic discharge (ESD) properties under those conditions.

A mini Mars chamber has also been constructed with an interior volume of about 1 cubic foot. Its primary use will be as a testbed for the development of the computer software to control the large and mid-size Mars chambers. It also has the potential to be used as a test facility for small Mars hardware.

A remotely controlled ESD test apparatus (called the ESD Robot) was designed and is being fabricated for use in the midsize Mars chamber. When completed, it will permit the testing of six sample material ESD properties during one cycle of the Mars chamber. Initial testing of the robot will be manually controlled in an ambient environment, and computer software will be developed to allow remote testing while in the chamber.

The Materials Science Laboratory (MSL) has been working with the International Organization for Standardization (ISO) in the development of cleaning procedures for space systems, components, and launch vehicles. These procedures are based on the KSC and Marshall Space Flight Center (MSFC) cleaning documents and will ultimately replace the current KSC cleaning documents. This is a vital effort for the International Space Station so all the user nations will have uniform cleaning procedures for flight hardware and components. The MSL has also supported the transferring of NASA compatibility test procedures into ISO test methods.

The Chemical Analysis Laboratory developed methods for determining parts-per-million amounts of hydrocarbons in replacement cleaning solvents and performed analysis of Shuttle aft gas samples after each flight. The lab analyzed Shuttle window wipes for particles after each flight and developed a method for the determination of trace amounts of helium in nitrogen gas using gas chromatography. The lab also investigated methods for the determination of the amount of sodium in Ludox, which can be directly related to the crystallinity and, hence, the effectiveness of the Ludox.

The ESD group in the MSL is collaborating with the Microdevices Laboratory at the Jet Propulsion Laboratory in the design, testing, and calibration of the MECA Electrometer for the Mars Surveyor 2001 mission, an electrostatic sensor consisting of an array of five triboelectric sensors, an electric field sensor, an ion chamber, and an internal thermometer. This instrument will provide a reliable method for measuring electric fields, ion charges, and electrostatic voltages generated on materials by triboelectric phenomena on Mars. Equipment onboard the Mars landers and rovers is susceptible to electrostatic charging when exposed to the fine dust lifted by winds during Martian dust devils and dust storms. These electrostatic charges could not only be attracted to critical surfaces, but may also generate dangerous electric potentials that may damage equipment and present hazardous conditions for future astronauts on extended missions to Mars. The levels at which these electric potentials can rise and their duration and effect on different materials are still unknown. This technology will provide answers to these unknowns.

The electrometer is currently being calibrated and tested under simulated Martian environmental conditions in the vacuum facilities at the MSL. Calibration curves will help to interpret the data received from the instrument on Mars.

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Remote Access, Internet-Based Data Acquisition System

Current outreach efforts for KSC's Beach Corrosion Test Site require all experimentation and data collection be conducted by on-site personnel on a real-time basis. This restricts the amount of work conducted at the site due to personnel constraints. A Remote Access, Internet-Based Data Acquisition System (RAIBDAS) would establish a basis for a corrosion technology testbed to allow personnel and customers to conduct their experiments from remote locations using the Internet.

This state-of-the-art pathfinder acquisition system could be utilized as a model for other NASA/KSC laboratories to directly develop their capabilities without the resulting impact to personnel and travel expenses. In addition, successful development and continued optimization of this system will produce great interest in NASA/KSC for corrosion research, corrosion exposure contracts, and industry partnerships. The benefits of this project include:

- Showcasing NASA/KSC's outreach efforts through interactivity and state-of-the-art technologies.
- Establishing a corrosion technology testbed for use by other NASA laboratories.
- Allowing direct outreach of the KSC Beach Corrosion Test Site to customers around the country and world.
- Allowing customers to conduct corrosion research without the travel requirements to the exposure site.
- Allowing business expansion at the site without the direct need for additional personnel.
- Developing network solutions to allow remote operation of experiment and data collection systems.
- Developing software with security features that allow outside customers to have data access at a KSC site.
- Testing the resulting systems to prove their feasibility and optimize user interface and expansion capabilities.

This interactive system will have significant commercial applications for outreach to the corrosion research laboratories, corrosion control industry, Government laboratories, paints and coatings industry, and marine technology industry.

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Participating Organization: Dynacs Engineering Co., Inc. (J.B. Crisafulli and J.J. Curran)

Evaluation of Corrosive Effects of De-Icing Chemicals on Steel Reinforcement in Concrete

The NASA Materials Science Laboratory, along with Dynacs Engineering Co., Inc., is evaluating the effect of a replacement for de-icing salts. Presently, sodium chloride (NaCl) and potassium chloride (KCl) salts are used to aid in the removal of ice from state highways. These salts are not material or environmentally friendly. These salts cause corrosion to bridges, roads, and associated structures. In addition, these salts affect the growth of roadside trees and vegetation. The two replacement formulations under study are a byproduct of feed used in the cattle industry. This byproduct is basically a corn alcohol with other chemicals added.

The current effort uses a laboratory test method based on the American Society for Testing and Materials standard ASTM G109, Determining the Effects of Chemical Admixtures on the Corrosion of Embedded Steel Reinforcement in Concrete Exposed to Chloride Environments. These test guidelines are used to evaluate the effect of de-icing chemical formulations on reinforcing steel in concrete. The ASTM G109 method is a relatively new method that is very adaptable for other evaluations, such as new reinforcing materials, new admixtures, posttreatment corrosion-inhibiting chemicals, new concrete design, and new concrete material testing. The effect of each chemical formulation is determined by electrochemical measurements and an autopsy of the reinforced concrete test blocks at the end of the test design cycle. The electrochemical measurements include reference half-cell potentials and corrosion current data.

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Participating Organizations: Dynacs Engineering Co., Inc. (J.J. Curran) and HITEC Project Manager (A. Murphy)

Electrostatic Discharge of Materials in a Simulated Martian Environment

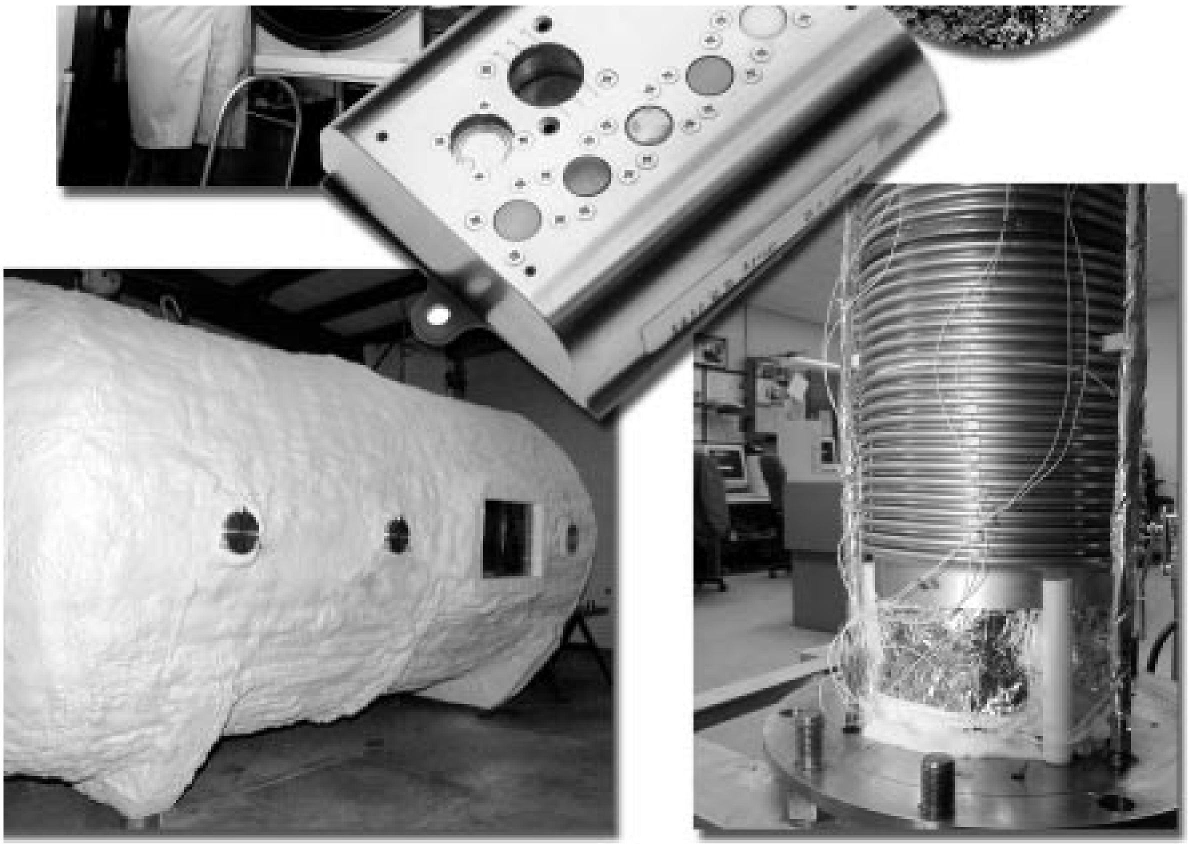
With its long tradition of testing and studying the electrostatic properties of films, the Materials Science Laboratory is engaged in experiments to learn about the electrostatic properties of the Martian regolith. Using a Martian regolith simulant prepared at Johnson Space Center, several techniques are currently being developed to measure the electrostatic discharge of the simulant particles and the generation of electrostatic charge by contact or friction with films and solids (triboelectrification).

The potential issues regarding the triboelectric properties of materials became significant with the recent Pathfinder Mission to Mars. The surface of Mars mainly consists of iron oxides and large amounts of very fine materials that are similar to talcum powder. Particles of this size pose special problems because they have increased mobility and can easily become attracted to oppositely charged surfaces from greater distances. The Martian environment is very windy (30 meters per second at peak velocity) with periods of low temperatures and extremely dry conditions. This provides ideal conditions necessary to generate triboelectric charging.

The project was initiated in March 1998. A vacuum chamber 40 inches in diameter by 60 inches in length was purchased in April 1998 and is in the final stages of modification. A robotic triboelectric tester was designed to operate remotely in the vacuum chamber. Initial checkout of the robotic triboelectric tester will begin once the chamber is completed. A Martian regolith soil simulant was obtained from Johnson Space Center to research the possible electrostatic charging of Martian sands. The soil simulant is volcanic ash from the Pu'u Nene cinder cone on the island of Hawaii. Consequently, a prototype was designed and built for the soil simulant delivery system. The prototype will simulate the Martian atmospheric movement of soil to determine if there is electrostatic charge generation on the selected materials. The research efforts in the upcoming year will focus on integrated automatic control of the vacuum chamber, testing the materials selected for the future Mars missions, and testing the simulant soil and materials at ambient conditions as well as in the Martian environment.

Key accomplishments:

- Designed and fabricated a Mars simulation chamber.
- Procured and upgraded the vacuum chamber.
- Obtained and analyzed the Martian regolith soil simulant.
- Built and tested the first proof-of-concept prototype for a soil simulant delivery system.
- Completed the robotic triboelectric tester.
- Wrote the electrostatic discharge proposal in response of 2003 and 2005 MITCH (Multi-Sensory Instrument for Total Climatological Hazard Assessment) payload.
- Participated in the design of 2001 Martian Environmental Compatibility Assessment (MECA) electrometers.
- Selected and recommended 2001 MECA patch plate materials.
- Completed the joint patent application with the Jet Propulsion Laboratory for unique electrometer design.
- Conducted a 2001 MECA electrometer test in a simulated Mars environment.
- Presented several papers on electrostatic discharge topics:



- 65th Annual Southeastern Section of the American Physical Society
- 193rd American Astronomical Society Meeting
- Electrostatics 99 Conference in Cambridge, England
- 5th International Conference on Mars
- Partner in Education and Research Conference
- Mars 2001 Workshop

Key milestones:

- March 2000: Complete fabrication and testing of the robotic triboelectric tester.
- May 2000: Complete testing and calibration of the MECA electrometer attached to the Mars robotic mission for the Jet Propulsion Laboratory.
- August 2000: Complete total integrated automatic control of the vacuum chamber.
- September 2000: Determine the triboelectric characteristics of the selected materials under vacuum conditions and in the simulated Martian environment.
- October 2000: Determine the triboelectric characteristics of the simulant soil at ambient conditions and in the simulated Martian environment.
- May 2001: Submit contribution to the electrostatics experiment package on the 2003 and 2005 Mars robotic mission. Identify and evaluate methods to reduce charge buildup on Mars Rover mission vehicles.

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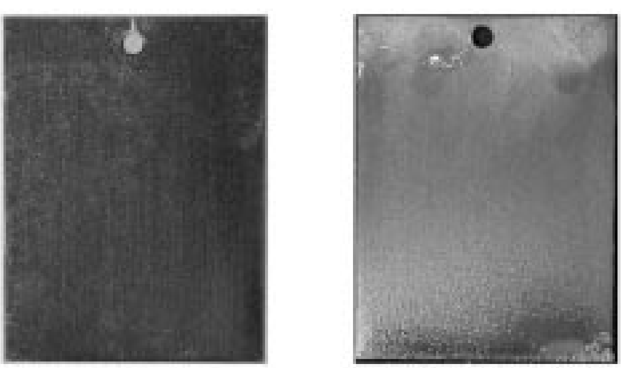
Molybdate Conversion Coatings for Aluminum and Alloys

An environmentally friendly aluminum coating for Government and industrial applications resulted from a collaboration between Lynntech, Inc. of Texas and KSC. Lynntech, of College Station, participated with KSC's Materials Science Division under a Small Business Innovation Research (SBIR) contract to develop a molybdate-based conversion coating for aluminum and aluminum alloys. This innovation, referred to as "Molyseal," is important because it does not contain chemicals or materials that are hazardous or toxic or that give rise to health and safety concerns. Lynntech applied for several patents relating to this technology and formed an alliance with multiple industrial partners in the metal finishing industry. Since Lynntech is a technology innovation and development company, its goals are to move this innovation to the precommercial stage, secure appropriate patents rights, and then license the technology to an interested manufacturer for entry into the commercial sector. The commercialization strategy includes third-party validation of the technology provided by leading end-users of chromium conversion processes through in-kind testing. Molyseal can be applied by dipping, painting, or spraying (with short treatment times at low temperatures) and is compatible with existing cleaning and pretreatment procedures. Only commercially available chemicals and materials are used that do not require special storage provisions and can be easily adapted into existing application methods. Lynntech envisions Government and science applications of this coating in the U.S. military's arsenal of missiles, NASA's spacecraft, and Department of Defense prime contractors. Industrial applications include aerospace, boilers, air conditioners, and aluminum construction materials.



(a) 0 Hour (B) 504 Hours

Appearance of Molybdate-Treated AL 2024-T3 (a) Before and (b) After Salt Fog Testing According to ASTM B117

NASA at KSC has used chromate-based coatings on many of its spacecraft and desires to replace these harmful chemicals with safer coatings. Until the successful formulation of Molyseal, NASA had no other alternatives. Future KSC operational use of this coating includes the Space Shuttle orbiter, the solid rocket boosters, and other NASA spacecraft and aircraft.

Use of chemical conversion coatings on aluminum alloys to achieve long-term corrosion resistance of painted spacecraft and aircraft structures has found widespread military and commercial applications. With increasing environmental regulations, the use of chemical conversion coatings that do not contain harmful chemicals is of particular interest to NASA, the Department of Defense, and other Federal agencies. The use of chromate-based conversion coatings generate health and safety concerns due to their toxicity and carcinogenic nature. Chromates have been found to cause irritation of the respiratory tract, ulcerations and perforations of the nasal septum, dermatitis, skin sensitization, asthma, and lung cancer. Alternatives for chromate conversion coatings that exhibit the same corrosion resistance and are formulated from environmentally acceptable chemicals are greatly needed. Lynntech has developed and tested a new type of molybdate-based conversion coating that provides both features. Tests demonstrate an exceptional corrosion resistance of the new coating prepared from formulations consisting of molybdates and several important additives. Some Molyseal coatings outperformed the chromate-based conversion coatings in electrochemical corrosion-resistance tests and passed a standard 336-hour salt fog test. These results established a sound technical feasibility for this new molybdate conversion coating.

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Development of Liquid Applied Coatings for Protection of Steel in Concrete

Corrosion of reinforcing steel in concrete is an insidious problem facing KSC, other Government agencies, and the general public. These problems include KSC structures, highway bridge infrastructures, and building structures such as condominium balconies. Due to these problems, the development of a galvanic liquid applied coating system (GLACS) would be a breakthrough technology having great commercial value.

Successful development and continued optimization of this breakthrough system would produce great interest in NASA/KSC for corrosion engineering technology and problem solutions. Commercial patents on this technology would enhance KSC's ability to attract industry partners for similar corrosion control applications. The present effort is directed at several goals:

- Phase I concentrates on formulation of coatings with easy application characteristics, predictable galvanic activity, long-term protection, and minimum environmental impact. These new coating traits, along with the electrical connection system, will successfully protect the embedded reinforcing steel through the sacrificial cathodic protection action of the coating.

- Phase II will improve on the formulations that include optimizing metallic loading and incorporating a humectant for continuous activation of the GLACS. In addition, development of optimum electrical connections will continue.

Laboratory testing has shown this technology to be feasible. Presently, testing is being conducted at the KSC Materials Science Beach Corrosion Test Site with positive preliminary results. In addition, the generated data is being collected and remotely accessed from off-site locations.

This new liquid applied coating system will protect existing KSC and NASA structures and will have significant commercial applications for the transportation infrastructure, marine infrastructure, civil engineering, and construction industries.

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Participating Organization: Dynacs Engineering Co., Inc. (J.J. Curran)

Long Flexible Cryostats for High-Temperature Superconducting Cables

The use of high-temperature superconducting (HTS) materials for power transmission applications is now being demonstrated in prototype situations. Future space applications for HTS materials, in addition to power transmission, include areas such as microwave communications, quantum devices, propulsion by plasma beams, and electromechanical actuators. From the refrigeration point-of-view, global proliferation of long-length power cable systems (flexible cryostats) will depend on an energy-efficient cryogenic system that is economical to manufacture and operate. An inherent element of these supporting cryogenic systems is the thermal insulation system.

A technology target of the Cryogenics Test Laboratory is the thermal management of HTS power transmission equipment for future energy needs on Earth and in space. A standard reference design for a mile-long flexible cryostat for power transmission is being developed as part of the Department of Energy's Superconducting Partnership Initiative. The thermal insulation performance levels of materials versus those of typical systems in operation have been described through extensive cryostat tests in the 77-kelvin temperature range. For Phase I development, a simulated section (1 meter) of a flexible cryostat has been constructed (see the figure). Measurement of the overall thermal performance of the simulated flexible cryostat under varied conditions of vacuum level and mechanical loading will be performed in 2000. These "real world" data will be compared with the thermal performance of the insulation material by itself, especially the multilayer insulation (MLI) type of material. This research study will be done in conjunction with the Oak Ridge National Laboratory.

Milestones:

- Phase II: Fabrication and test of a prototype long flexible cryostat using the existing pipeline test apparatus. The objective is to measure and compare the thermal performance of long flexible cryostats under simulated field conditions.
- Phase III: Test integrated HTS cable and refrigeration systems under dynamic flow conditions.

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Participating Organization: Dynacs Engineering Co., Inc. (S.D. Augustynowicz)

Thermal Performance Testing of Simulated Flexible Cryostat for a Superconducting Cable

Corrosion-Resistant Tubing for Space Shuttle Launch Sites

The existing 304 stainless-steel tubing at Launch Complex 39 (LC-39) launch pads is susceptible to pitting corrosion. This pitting corrosion can cause cracking and rupture of both high-pressure gas and fluid systems. The failures can be life threatening to launch pad personnel in the immediate vicinity. Outages in the systems where the failures occur can affect the safety of Shuttle launches. These failures have been documented in reports, such as MSD Report 95-1M0040.

Improved corrosion-resistant tubing systems will greatly enhance both personnel and Shuttle safety concerns. These new-generation materials will require less maintenance over their lifetime and significantly reduce costs associated with these systems. A program is in progress to:

- Identify domestic fabricators/suppliers of seamless annealed tubing of corrosion resistant alloys.
- Procure samples of the tubing for evaluation.
- Fabricate tubing test articles.
- Expose test articles at the KSC Beach Corrosion Test Site with concurrent applications of acidic slurries to simulate solid rocket booster deposits.
- Evaluate the performance of various tubing alloys for corrosion resistance.
- Determine performance/cost benefits to recommend new material for LC-39 applications.

This program will provide the following benefits:

- Corrosion-resistant tubing in launch pad applications will greatly reduce the probability of future pitting corrosion failures.
- Improved safety and lower maintenance costs will result from using more corrosion-resistant alloys.
- All launch pad high-pressure gas and fluid systems will have increased reliability.

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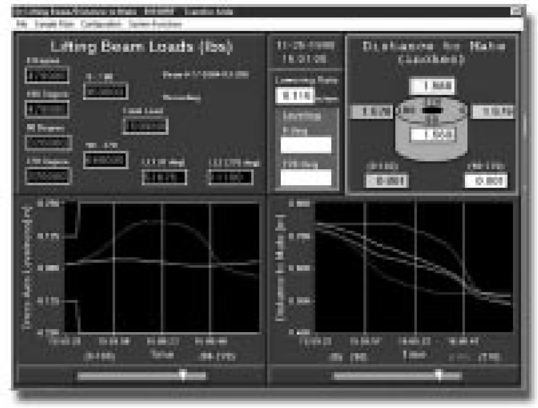
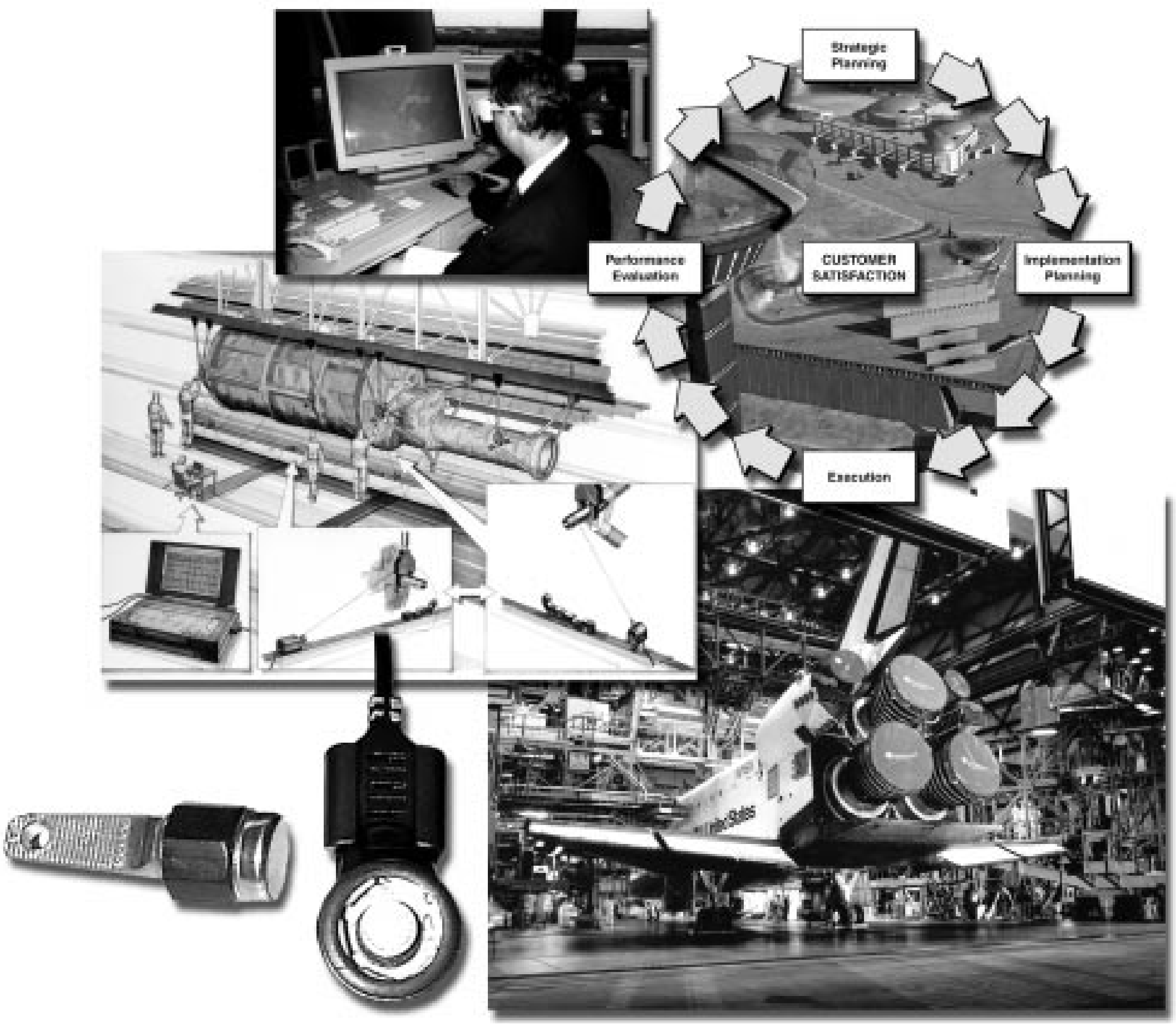
Participating Organization: Dynacs Engineering Co., Inc. (J.J. Curran)



Process Engineering



Management Support Systems: Project and Resource Management System

KSC requires a system to help plan and track information on projects, expendable launch vehicle (ELV) missions, and resources utilized for these efforts. This system must support the subprocesses specified in NPG 7120.5A, NASA Program and Project Management Processes and Requirements, and help upper KSC management plan and track the allocation of its manpower and financial resources and forecast its future skill requirements. To fulfill these requirements, KSC is developing a Project and Resource Management System (PRMS).

The PRMS will support the formulation, approval, implementation, and evaluation of Center projects and ELV missions. The system will provide a "one-stop-shopping" repository for information on projects and missions. The system will store many types of project data, including details on customers, related documents, strategies, tasks, and milestones, required roles and the people filling those roles, budgets, planned and actual expenses, issues and action items, deliverables, and associated contracts. ELV missions are considered to be a special class of PRMS projects. Mission data includes all the information specified for projects as well as details about the spacecraft, launch specifics, and windows. The PRMS will be composed of three subsystems:

1. Detailed Project Management Subsystem (DPMS): KSC Project Managers and ELV Mission Integration Managers will utilize the DPMS for their day-to-day project planning and tracking. The DPMS builds on capabilities of a commercial off-the-shelf project management product (Microsoft Project 98).

2. Midlevel Project Management Subsystem (MPMS): Relevant data from the DPMS can be transferred up to the MPMS. The MPMS provides a one-stop-shopping information center for project team members, middle management, customers, and other stakeholders. It also provides required reporting needed for periodic program and project reviews. The MPMS stores information in a commercial enterprise relational database (SQL Server 7) and utilizes industry standard Web browsers (Netscape Navigator or Internet Explorer) for its graphical user interface (GUI).

3. KSC Strategic Management Subsystem (KSMS2): Relevant data from the MPMS will be utilized in the KSMS2. This subsystem will allow senior management to ensure the Center's resources are effectively applied to meet NASA's needs. PRMS will also provide skill assessment, evaluation, and gap analysis integration into the project management infrastructure.

The PRMS development effort was initiated in June 1998. The project is being developed using an evolutionary incremental release strategy. As of October 1999, there have been three major deliveries. A system with basic MPMS and DPMS functionality will go into initial production during January 2000. Development of enhancements and follow-on deliveries are scheduled to continue through calendar year 2000, and a transition to an operations and maintenance phase is scheduled to occur in early calendar year 2001.

The PRMS is already integrated with many other KSC Enterprise Information Technology (IT) Systems and utilizes KSC's master NT domain for account authentication. The system obtains employee information from the X500, KSC Exchange, and Pass Badge Management Systems, and utilizes KSC's ISO 9000 Technical Documentation System (TechDoc) for its document management. The PRMS will soon tie into KSC existing financial system to obtain actual expense information. In the future, the PRMS may also be integrated with other relevant IT systems. The PRMS will provide an overarching integrated project management infrastructure. The PRMS is expected to serve KSC at large. It will be made available to all NASA organizations and potentially to all their contractors.

Key accomplishments:

- June 1998: PRMS project formulation initiated.
- August 1998: Software concept and initial project plan approved.
- October 1998: PRMS Release 1, the KSC skills assessment application delivered and put into production.
- November 1998: Approximately 1200 NASA employees logged into the system and completed the 1998 KSC Skills Assessment Survey. This data was used to create KSC's 1998 Core Competency Analysis.
- January 1999: PRMS Release 2, the MPMS prototype delivered and made available to user communities for testing.
- September 1999: PRMS Release 3, MPMS enhancements and initial DPMS prototype delivered and made available to user communities for testing.

Key milestones:

- December 1999: Development completed for PRMS Release 3A. This release provides initial integration of PRMS with KSC's existing financial systems. The PRMS production servers for KSC projects and ELV missions will become operational.
- January 2000: PRMS Release 3A rolled out into production.
- February 2000: PRMS Development Team and Control Board will reprioritize future work packages in remaining releases and schedule those releases.
- July 2000: Current estimate for PRMS Release 4.
- January 2001: Current estimate for PRMS transition to operations and maintenance phase.

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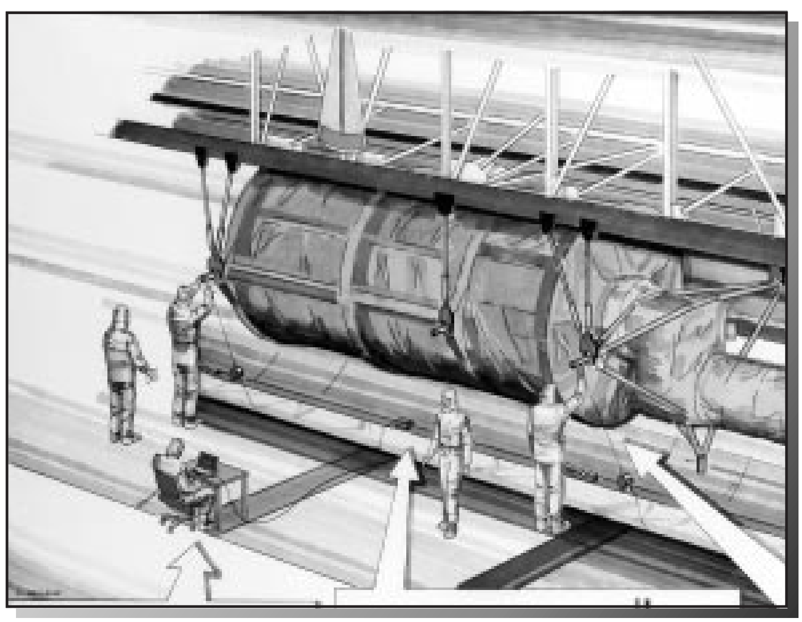


Example of PRMS MPMS Project/Mission Details Data Entry Form

Management Support Systems: Software Project Risk Analysis

Software risk identification and analysis help project managers understand the nature of the schedule and cost risks their projects face. The research into software risk analysis was implemented under a Phase II Small Business Innovation Research (SBIR) contract. A methodology for software risk identification and analysis was developed. Risk identification and analysis is part of an overall risk management methodology where the "front end" tasks are identification and analysis and the "back end" tasks are planning, tracking, and resolving risk. See figure 1.

Risk identification defines the activities and methods used to discover risks. The risk identification process should encourage input of perceived risk from the software development team and identify and document sources of risk while there is time to take action. The steps in risk identification are: (1) defining a risk assessment methodology, (2) systematic identification of risk, (3) definition of the attributes of each identified risk, (4) definition of the tasks for which there is risk, (5) documentation of the risks, and (6) communication of the risks.

Once a database of risks has been identified, along with the corresponding tasks, a risk analysis can be performed. The basic purpose of the risk analysis is to prioritize the risk list. In addition, risk analyses can provide insight into the collective risks on each task and work breakdown structure element and the collective risk due to each risk type.

Because the methodology is based on the Software Engineering Institute (SEI) recommendations, the methodology was named the "SEI-derived" risk identification and analysis (SEI-RIA) methodology. The suggested methodology is closely related to

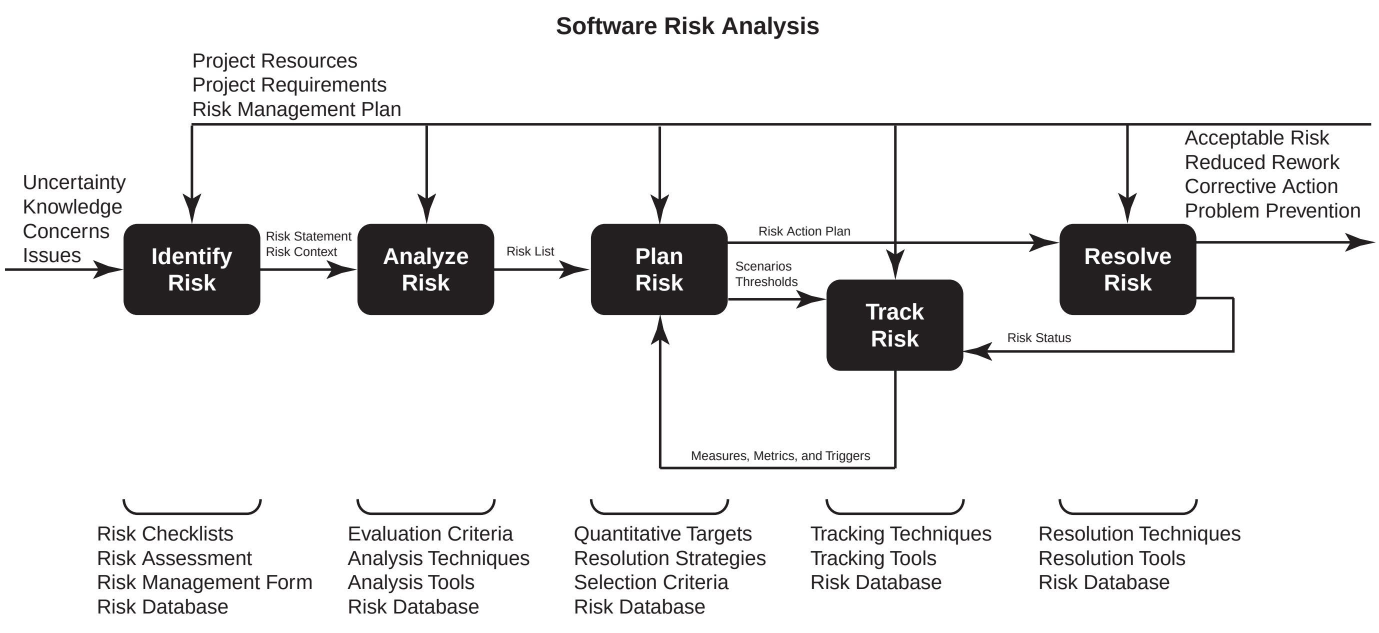
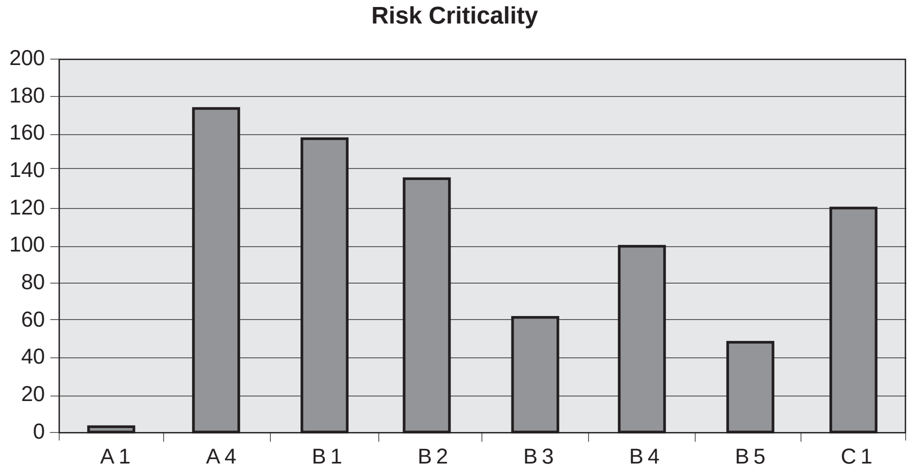


Figure 1. Software Risk Analysis Methodology



Notes:

A1 = product engineering – requirements
A4 = product engineering – integration and test
B1 = development environment – development process
B2 = development environment – development system
B3 = development environment – management process
B4 = development environment – management methods
B5 = development environment – work environment
C1 = program constraints – resources

Figure 2. Example of Risk Criticality Report

current risk identification and analysis methodologies being used operationally. The SEI-derived methodology adds:

1. An industry-accepted taxonomy of risks

2. A questionnaire that helps software managers think through the risks on tasks for which they are responsible

3. A well-defined vocabulary for specifying (qualitatively and quantitatively) the probability of a risk and the consequences of a particular risk

4. A risk prioritization methodology that takes into account probability of risk, schedule risk, cost risk, and task criticality

These four improvements in the methodology allow many additional kinds of risk analysis to be performed; for example, reports on the importance of different risk categories will be possible. See figure 2.

The methodology was applied to a small part of a large software project being developed at Kennedy Space Center and the results were promising.

Key accomplishments:

- 1998: Software project risk analysis methodology developed.
- 1999: Risk analysis methodology applied to KSC software project. Analysis results and final report delivered to project team.

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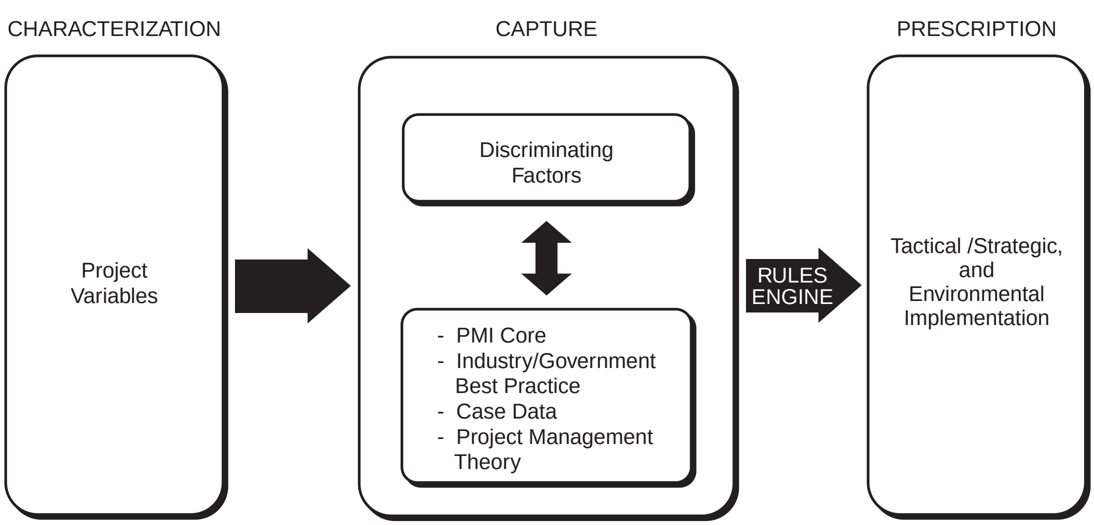
Participating Organizations: Fair Isaac, Inc. (R. Fung) and United Space Alliance

Management Support Systems: Strategic Project Management Process Model

As a result of 10 years of strategic management planning, KSC is currently transitioning to maintain and strengthen its valuable role within the NASA Agency. The transition is from a space center that focuses on technology sustenance and operations to a center engaged in research and development, knowledge creation, and oversight/insight activities. As such, in the future more and more organizational resources at KSC will be managed in project settings. Time, cost, quality, and safety performance goals require that organizational resources be actively managed throughout entire project life cycles to ensure project goals, objectives, and deliverables. The Strategic Project Management Process Model (SPMPM) is developed to assist KSC as it builds appropriate project management processes. The model involves three distinct modules as illustrated in the figure and is developed upon the assumption not all project management processes are appropriate for all classes of projects in all environments and for all types of project goals and objectives. In a prescriptive fashion, the model defines and describes the project management processes appropriate for specific classes of projects. At KSC, appropriate processes will be developed and utilized based on the characteristics of the projects being managed. Such an approach ensures all projects have processes that will lead to the achievement of goals and objectives, including the integration of technical and nontechnical issues.

The characterization module of the model delineates all possible differentiating project variables, including tactical, strategic, and environmental perspectives (as well as others). The capture module of the model classifies these general characteristics into meaningful discriminating factors from which groups of projects can be distinguished. Once captured, the prescriptive module prescribes the particular key project management processes most appropriate for a given class of projects. A “rules” or “knowledge” engine is used to go from the classification to the prescriptive modules of the model.



Strategic Project Management Process Model

This engine serves to process the specific requirements of the captured class of projects to produce the prescriptive output.

The SPMPM is appropriate for organizations developing or establishing new project management processes. It can be used by organizations that currently have operational processes as a tool to evaluate those existing project management processes and offer recommendations for improvement for a higher level of organizational goal attainment.

Key accomplishments:

- 1999: Development of the SPMPM framework and working issues for KSC development.

Key milestones:

- 2000 and 2001: Continue development of model modules, implementation, and integration issues at KSC.

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Participating Organization: Kansas State University (J. Lavelle)

Management Support Systems: Organizational Change Models for Strategic Management

Government organizations, as is the case with private organizations, are being required to change their present operations to align with the ever-changing environment. Often this leads to a large-scale transformation including a change in mission or core business. With the change in mission, the organization must also change the manner in which it completes its core business (i.e., the processes, tools, and people). One of the first steps in achieving successful change and transformation is to create a vision of the future. Strategic management has been offered as a method to drive organizational change. Strategic management is a continuous process aimed at aligning everyday actions with the long-term direction of the organization based on the needs of the customer. An organization can use strategic management to achieve a set of strategic thinking outcomes and develop a set of products to move the organization forward. The objective of this research is to understand and demonstrate the use of the strategic management process to drive large-scale transformation.

As shown in the figure, the process of strategic management includes the functions of strategic planning, implementation planning, execution, and performance evaluation. KSC initially used this process to define and develop a strategic vision and direction, strategic plan and roadmap, project plans, an initial set of performance measures, strategic results, and lessons learned.

During this second full cycle of strategic management, KSC refined its strategic vision for the future. The Center's objectives and strategies were updated in the KSC Roadmap. Projects focused in strategic areas were developed and approved. The Center Director again shared an update of the Center's progress and achievements in a televised all-hands address to employees, and the Executive Team followed up with smaller meetings with each directorate to share details of the Center's future vision and discuss specific relevance to each organization. In an effort to disseminate strategic management more broadly, training was offered to over 300 leaders across the Center. These sessions provided the opportunity to teach lessons in strategic theory as well as collect valuable data from the work force pertaining to KSC's challenges and areas of opportunity. Efforts continued to more closely align strategic management processes with the Center's customer focus activities and Balanced Scorecard. In a truly integrated environment, these elements will provide ongoing information for KSC to determine how to best meet and exceed customer needs and create tangible results that can be studied and fed back into the strategic management process. This will enable continuous improvement of the Strategic Plan and ensure KSC is postured to achieve its future vision.

Key accomplishments:

- 1997: Conducted an internal and external research study on the success factors for strategic management.
- 1998: Conducted a cycle of strategic management with KSC.
- 1999: Refined a set of processes and integrated a schedule for strategic management. Developed a best-practices model for deploying strategic management. Conducted training of over 300 NASA leads and supervisors in strategic management as an element of KSC's Leadership Excellence Achievement Program (LEAP). Con-

ducted a detailed survey to identify the outcomes and enablers of strategic management.

Key milestone:

- 2000: Develop and deploy an integrated approach for strategic thinking throughout the organization, directorates, and projects.

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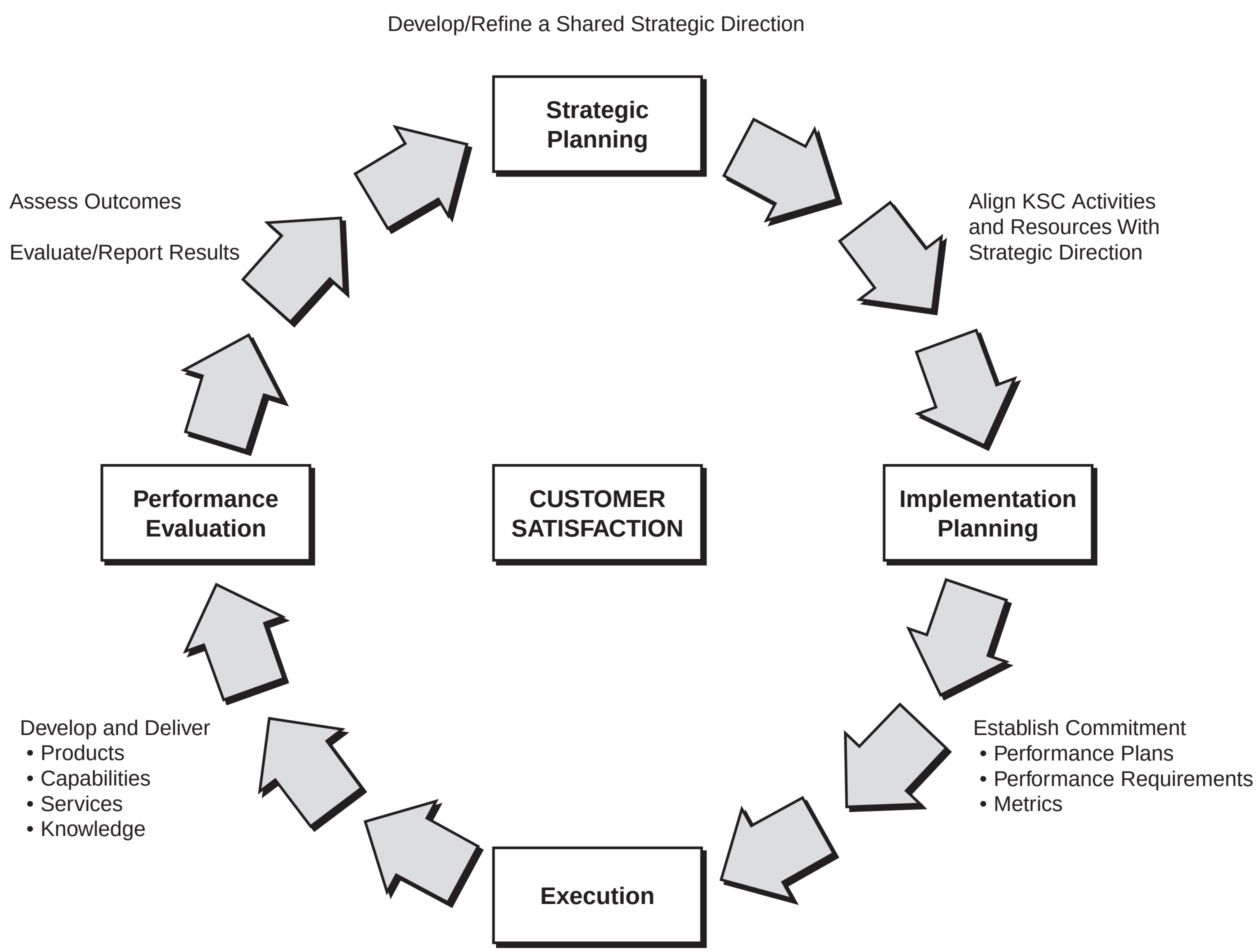
Participating Organization: University of Central Florida (T. Kotnour, Ph.D.)



Strategic Management Process

Management Support Systems: Change Management and Analysis Tool

A prominent characteristic that distinguishes successful enterprises of the next millennium will be the ability to respond quickly, proactively, and aggressively to unpredictable change. Robust methods and tools to facilitate change management are therefore an essential requirement for the modern enterprise. Recent advances in strategic planning techniques, the emergence of global and virtual corporations, and rapid advances in information technology have helped address many key change management needs. However, most change management technology developments address problems at the tactical level (for example, business process reengineering methods and continuous process improvement methods). There are significant technology gaps and challenges associated with strategic change management. Specific technical voids include: (1) lack of scientific methods for strategic change management, (2) lack of information-integrated software tools to support the change management process, and (3) lack of knowledge management mechanisms that capture, store, and leverage corporate knowledge for strategic planning and control.

While most organizations have some sort of vision statement (for example, "to become the industry leader by 2003"), they generally do not have a structured method to articulate, monitor, control, and manage their strategic vision. The Change Management and Analysis Tool (CMAT) was designed to address this problem. CMAT is envisioned to be a tool that helps capture and detail a vision, generate alternate ways of achieving the vision, provide support to decide on the optimal manner to achieve that vision, and finally monitor incremental progress towards accomplishing that vision. The output of CMAT, a set of specific strategic initiatives, may then be implemented using a Balanced Scorecard tool.

The CMAT is a knowledge-based environment that would enable NASA to evaluate the current status in strategic terms and to define unambiguously where it would like to be at the end of the strategic planning horizon. Given the direction of change, the CMAT would aid in generating, documenting, evaluating, and prioritizing the strategic initiatives that will help transform the organization from the current state to the envisioned future state. It would also allow NASA to monitor the performance of strategic initiatives vis-à-vis the strategic goals of the organization. The CMAT Phase I project objectives were to:

1. Develop an understanding of the KSC strategic planning process.

2. Define the CMAT requirements.

3. Define the strategic planning methodology.

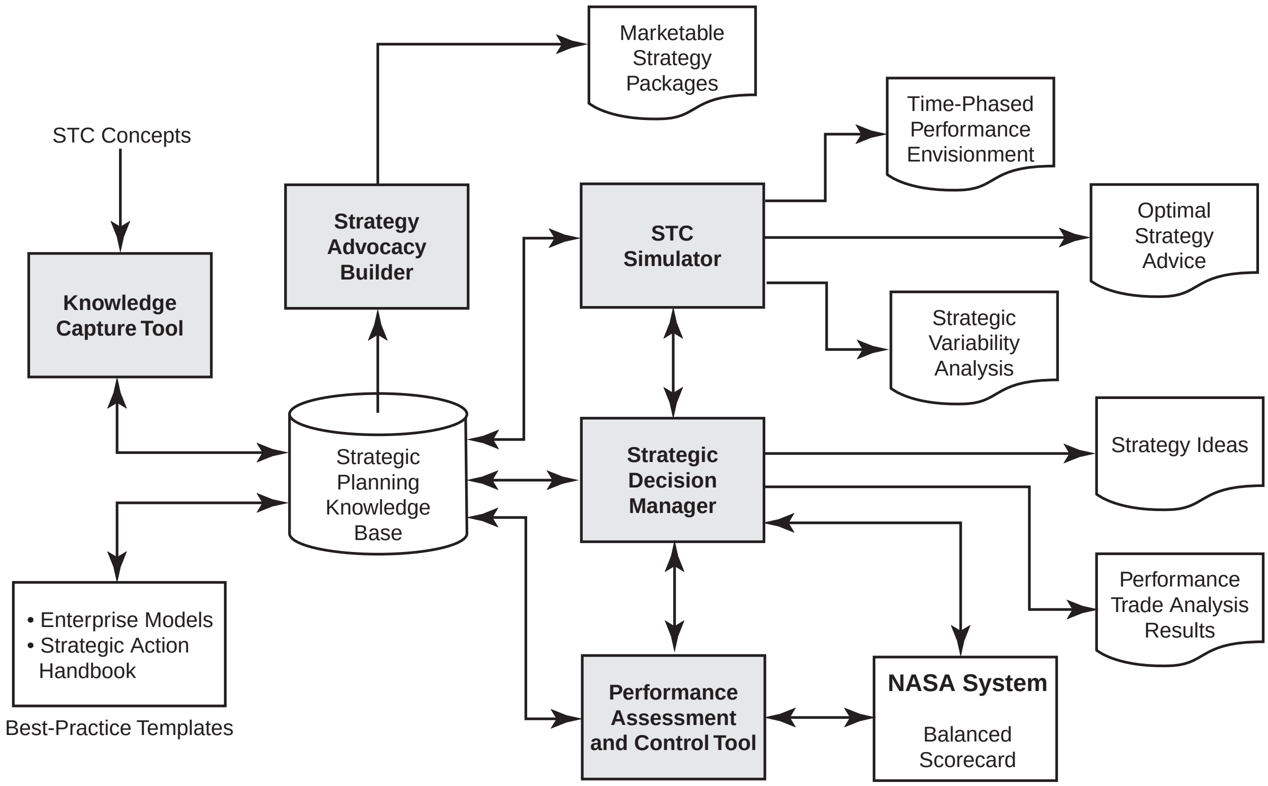
4. Design the CMAT.

5. Develop a detailed concept of operation for the CMAT.

6. Develop and demonstrate a proof-of-concept CMAT.

7. Develop the Phase II approach and Phase II proposal.

The figure shows the CMAT architecture. The Strategic Decision Manager (SDM) will facilitate



CMAT Architecture

the generation of ideas for new strategic initiatives, the grouping of initiatives into collections called packages, and the generation of time-phased trade-off analysis information that shows the costs and expected benefits based on multiple criteria. The Spaceport Technology Center (STC) Simulator generates variability/risk assessments for each package, risk-adjusted optimal strategy selection advice, and time-phased envisionments of predicted performance and variability. The Strategy Advocacy Builder (SAB) assists the collection and organization of information to help build advocacy for the packages and generates marketable strategy packages. The Performance Assessment and Control (PAC) tool assesses the performance of implemented initiatives, determines deviations of performance from projections, and generates recommendations for revising strategies based on these assessments.

Key accomplishments:

- 1999: Completion of Phase I SBIR contract. The architecture design for CMAT. CMAT concept of operation. Best-practice STC templates. Development of the prototype CMAT.

Key milestones:

- 2000: Potential project continuation at KSC. Application of the CMAT to support ongoing work at Tinker Air Force Base.

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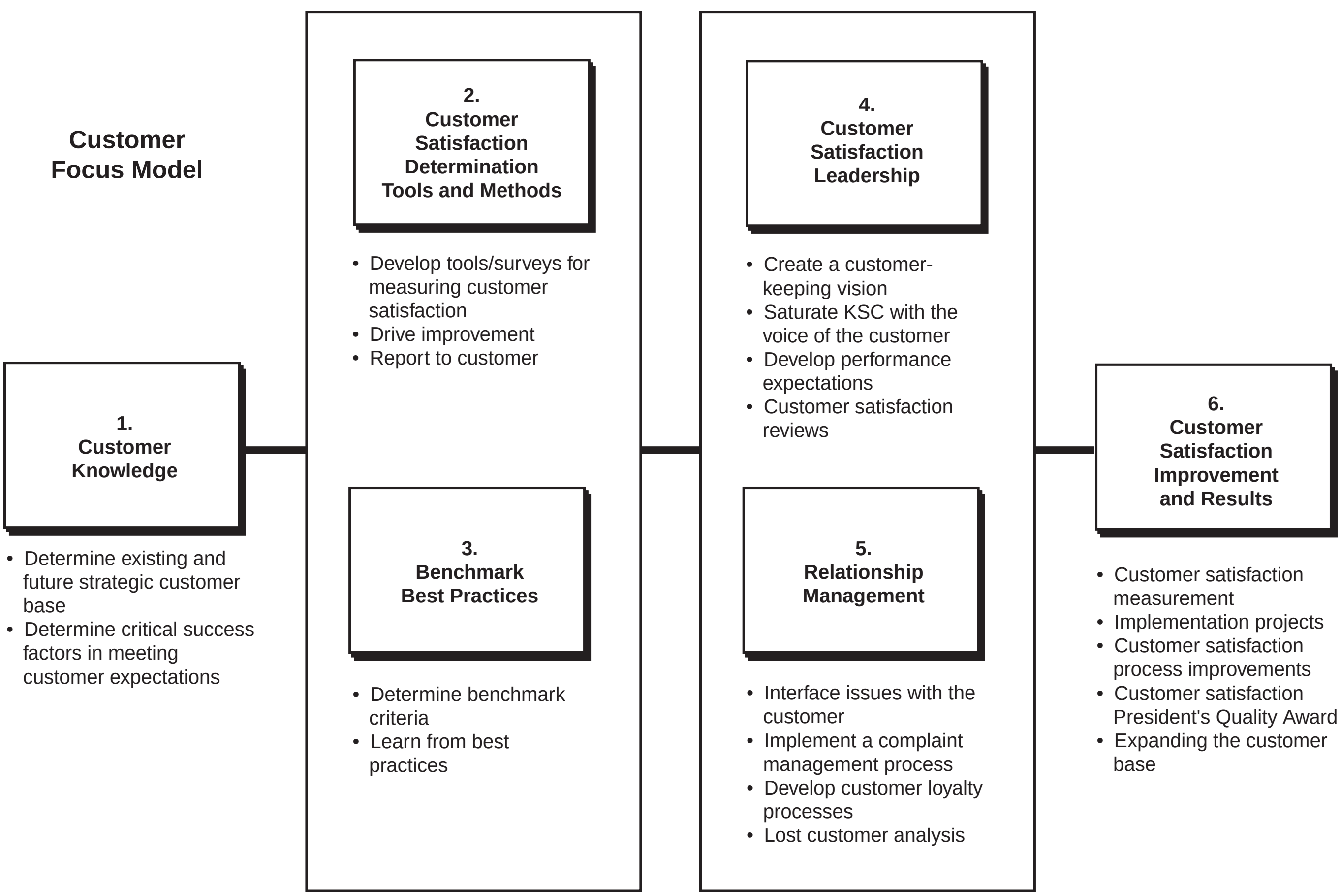
Participating Organization: Knowledge Based Systems, Inc. (Dr. P.C. Benjamin and M. Erraguntla)

Management Support Systems: KSC Customer Focus Process Development

As part of the KSC Strategic Roadmap, customer satisfaction has been identified to be both an objective and a strategy. These customer satisfaction objectives and strategies will support the Center's vision and will help in achieving KSC's stated goal as the worldwide launch site of choice. The objectives and strategies will also drive improvements in KSC's core capabilities by addressing the tools, expertise, facilities, and business processes that support the customer. To address these customer satisfaction objectives and strategies, research was conducted in customer satisfaction, which included customer elements from the Baldrige award criteria and President's Quality Award. Based on the research, a customer focus model was developed (see the figure). The model delineates a six-element scope defined as follows:

1. Customer Knowledge: This element defines and segments current and potential strategic customers and identifies their needs, with additional information gathered regarding their requirements, expectations, and critical success factors.

2. Customer Satisfaction Determination Tools and Methods: These processes include collecting feedback from multiple types of methods over the duration of the customer experience at KSC, feeding that information back to the appropriate organizations, using the information to drive improvement projects, and reporting the improvements back to the customer.



3. Benchmark Best Practices: Benchmarking becomes an ongoing process of seeking out continual improvements in both the practices and processes of improving customer satisfaction.

4. Customer Satisfaction Leadership: This element uses the previous element results to create a customerkeeping vision, to saturate KSC with the voice of the customer, and to develop performance expectations related to customer focus.

5. Relationship Management: Relationship management uses processes for interfacing and supporting the customer to maximize customer loyalty and retention and to analyze complaints.

6. Customer Satisfaction Improvement and Results: This element develops and tracks customer service standards based on outcomes from the previous elements, including customer satisfaction metrics and customer business results for KSC.

This model is being used as the blueprint to develop and implement processes and leadership for a customer-driven KSC. Once implemented, the results of the processes will be used as an integral component of the Center's strategic planning efforts.

Key accomplishments:

- 1998: Identified and segmented the KSC customer base. Surveyed KSC management for perceived barriers and enablers of customer satisfaction. Completed a test case for the first segment for customer satisfaction determination. Reported the test case results to senior management and to those customers interviewed.
- 1999: Completed a major survey project that segmented customers based on the customer's perception of their need for technical and interface complexity. The results of the survey produced a revised segmentation grouping and a menu of Florida Launch Site products and services. Implemented an internal/external "Opportunity for Improvement System" to allow for comment feedback to be collected and managed electronically. Implemented an external website to increase the customer's knowledge of KSC's capabilities. Implemented an internal website to increase employee awareness of customer needs. Developed and engaged a cyclical survey tool to collect senior manager evaluations of the evolution of customer focus. Coordinated and facilitated a Centerwide customer service week to raise employee awareness of customer service principals.

Key milestones:

- 2000: Establish and use processes for ongoing customer satisfaction and feedback collection and measurement. Begin identifying and testing customer relationship management approaches that will increase customer loyalty.
- 2001: Implement feedback system across all products and services. Implement technologies that will facilitate seamless integrated customer interactions and management.

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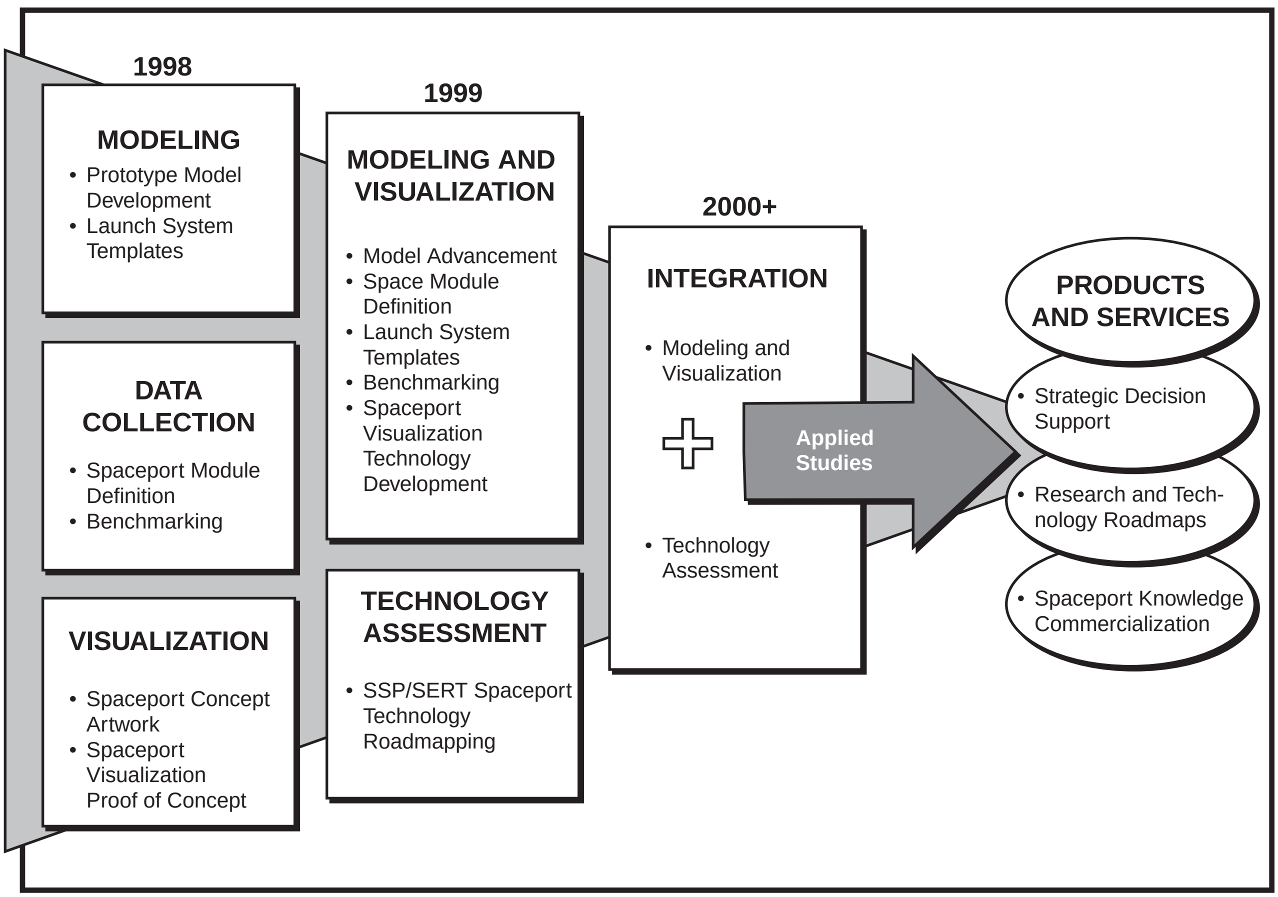
Participating Organizations: University of Central Florida (J. Matkovich and T. Kotnour) and the KSC Customer Focus Team (NASA, United Space Alliance, and Boeing)

Process Modeling and Analysis: Vision Spaceport Model Development

Analysis of the world's space transportation systems reveals excessive costs, continual launch schedule delays, and failure of the systems to achieve aircraft-like capability. None have yet achieved a level of payload delivery capacity needed to open space as a routine, affordable destination. The tonnage of worldwide delivery of payloads to Earth orbit has failed to increase in accordance with many business model predictions for over 10 years, reflecting the impact of extraordinary space transport costs. System affordability and increased spaceport payload throughput is essential to enable the opening of space as a viable business frontier.

As the Center of Excellence for Launch and Payload Processing Systems, KSC initiated a Joint Sponsored Research Agreement in July 1998 to examine generic launch site operations and infrastructure cost-driving factors. This agreement, wherein the Government, industry, and academia partners contribute resources to accomplish the project, is taking on the task of influencing spaceport systems-design interfaces with launch vehicles of the future. The partnership is identifying candidate technologies showing promise to enable revolutionary spaceports of the near future that provide effective, affordable space transportation.



Government/Industry/Academia Source of Spaceport Technology Knowledge

The partners form a consortium known as the Spaceport Synergy Team that consists of launch site analysts and engineers who have developed an initial proof-of-concept operations-cost core model. This innovative model incorporates a database encompassing historical performance of key launch systems. Elements of strategic investments in spaceport/vehicle interactive technologies that hold promise to enable systems and operations leading to affordable space transportation are being identified.

When model release 1 is completed and validated during 2000, emerging-concept design criteria can be entered into the model and compared to known operations cost-driver data embedded in the model database. Space transport system-concept performance can thereby be thoroughly estimated in relation to historically documented cost and performance data.

For a wide variety of near-future launch vehicle concepts and technologies, the model is designed to identify, at a top level of resolution, the required launch site facilities, vehicle processing cycle times, recurring operations costs estimates, operational work force size, facility acquisition cost estimates, and system flight rates. The core model focuses on 12 spaceport functional modules: payload cargo processing, landing/recovery, vehicle depot maintenance, operations planning and management, traffic/flight control, vehicle turnaround, spaceport infrastructure, expendable elements, launch facilities, vehicle assembly/integration, concept-unique logistics, and community infrastructure.

Key accomplishments:

- 1998: Modeling (prototype development and launch system templates); data collection (spaceport module definition and benchmarking); and visualization (spaceport-concept artwork and spaceport visualization proof-of-concept).

- 1999: Modeling and visualization accomplishments (from prototype to working application): restructured knowledge base, visualization "port-to-PC" demonstrated, enhanced core model-visualization integration, and object library updated.

- Technology Assessment (established structured assessment/prioritization process): funded by NASA Space Solar Power (SSP) Exploratory Research and Technology (SERT) program; customer/stakeholder interviews conducted to determine desired spaceport attributes; spaceport attributes and design features ranked and prioritized; and electronic "canvassing" survey forms prepared for populating a prototypical candidate database.

Key milestones:

- 2000: Develop tools/products and services capabilities to continue maturation of core model support databases (architecture and visualization integration), to develop spaceport technologies investment strategies and risk/benefit insight (assess technologies), and to support applied studies (SSP/SERT and the SpaceLiner 100 technology program).

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Participating Organizations: Ames Research Center; The Boeing Company; Command and Control Technologies; Lockheed Martin; Quantum Technologies Services, Inc.; Science Applications International Corporation; and University of Central Florida

Process Modeling and Analysis: Intelligent Assistant for Optimization Modeling

The versatility of optimization modeling has, over the last 40 years, established it as a popular decisionmaking aid. Optimization encompasses a suite of powerful decision support paradigms that enable the modeling of any decisionmaking environment in terms of the objectives, decisions influencing the objectives, and constraints binding the decisions. However, the potential of these powerful techniques has remained largely unharnessed due to the following inherent difficulties in constructing optimization models:

1. Optimization models typically address aspects of the domain that are often hidden or invisible to casual observers.

2. Highly specialized skills are required to design and generate executable models.

3. Optimization-based decision support systems typically depend on building custom solutions for different domain situations.

4. Few available tools are able to leverage the expertise of domain experts.

Preliminary research to alleviate these difficulties was conducted under a Phase I Small Business Innovation Research (SBIR) contract. The central product of this effort was a prototype implementation of the Optimization Modeling Assistant (OMA). Several key Phase I objectives were realized during this initial effort. The research team developed a structured method of optimization model development and created a structured, ontology-based method for knowledge acquisition and analysis. Another key objective was to develop a knowledge base of heuristics, principles, and rules that assist in optimization model development. Templates were created that encapsulated the knowledge of optimization modeling paradigms for both application-specific and generic modeling.

The Phase II technology hardening efforts identified another important factor that limits widespread application of optimization techniques to practical problems: the unavailability of much of the information needed for developing optimization models. While optimization techniques provide analytically sound solutions, their success hinges on the availability of accurate input data. Often, the input data required to develop valid optimization models does not exist or is inaccessible in most domains. Recognizing this, Knowledge Based Systems, Inc., (KBSI) expanded the architecture of the Phase II OMA to include simulation-based optimization. Simulation will be used to generate the necessary input data, which is then used by OMA for optimization. Using the two powerful decision support techniques together, OMA will deliver comprehensive decision support analysis capabilities to managers and decisionmakers. The enhanced OMA software implementation was completed in 1999 (see the figure).

Phase III activities planned for 2000 include (1) exercising the OMA software with KSC domain data, (2) refining the OMA commercial products, and (3) developing OMA applications for sustainment and remanufacturing at Tinker Air Force Base, Oklahoma City, Oklahoma, as part of another Phase II SBIR initiative.

Key accomplishments:

- 1996: Completion of the Phase I SBIR contract. Development of the prototype OMA. Selection for Phase II follow-on research.
- 1997: Defined the OMA prototype and templates. Designed OMA extensions for simulation-based optimization. Developed KSC process models for OMA application.
- 1998: Prototyped simulation-based optimization. Completed the OMA implementation. Acquired KSC domain data for OMA application.
- 1999: Completed the OMA demonstration at KSC. Developed the OMA application at Tinker Air Force Base. Developed the commercial OMA software.

Key milestones:

- 2000: Continue OMA commercialization and OMA application at KSC and Tinker Air Force Base.

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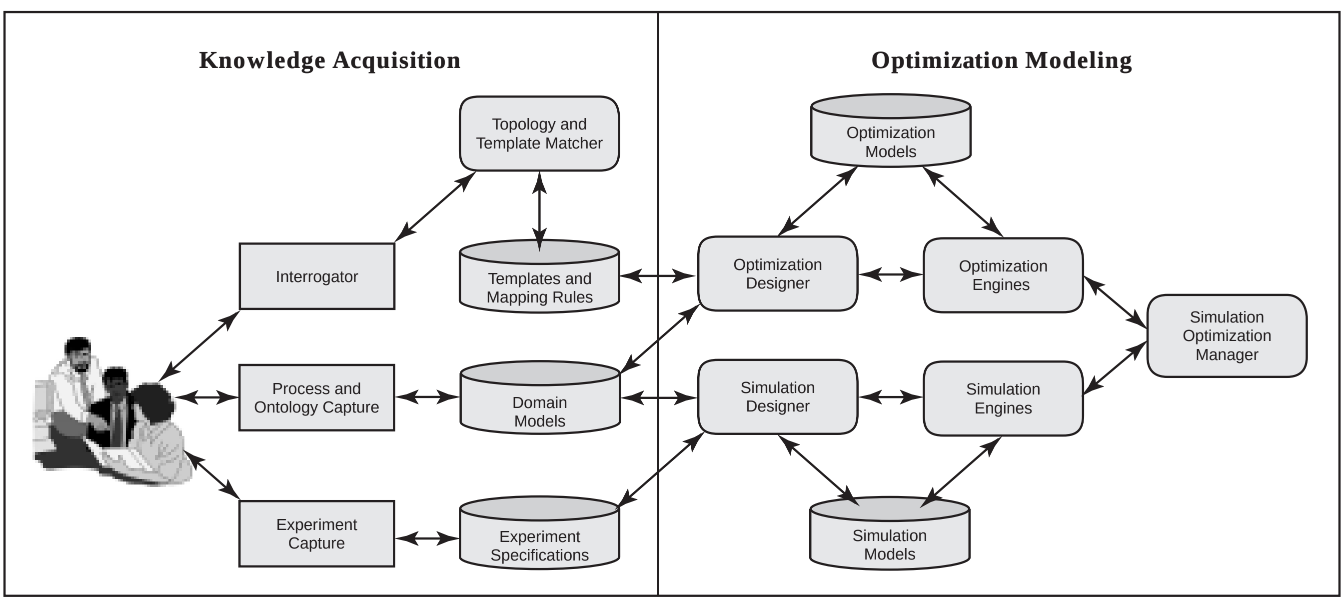
Participating Organization: Knowledge Based Systems, Inc. (Dr. P.C. Benjamin)



OMA Conceptual Architecture

Process Modeling and Analysis: Process Improvement Expert

A variety of appropriate statistical process control and improvement techniques exists that can be used successfully in aerospace applications. However, the complexities of identifying the appropriate technique, conducting the analysis, and interpreting the results minimize the actual application of these techniques in aerospace and many other industries. While numerous statistical software packages are available, these packages require considerable knowledge of statistical techniques for successful implementation. Most of these statistics packages are designed for a broad range of applications and include many functions that are unnecessary in an industrial processing and design environment, thus further complicating the use of the products. A software package that incorporates the most valuable process monitoring and improvement techniques in an easy-to-use-and-interpret format will have considerable benefit in aerospace and many other industries. This package will benefit KSC directly by providing engineers, technicians, and managers with a tool that can reduce processing costs while improving quality. Application areas in KSC operations include Shuttle processing, reliability-centered maintenance activities, payload processing, space station processing, logistics, human factors monitoring, and business operations.

A Phase I Small Business Innovation Research (SBIR) contract was awarded to Optimal Engineering Solutions, Inc., to explore the possibility of developing an expert system software package that would enable users to conduct process monitoring and improvement activities in an aerospace environment. During Phase I, the following activities were completed: review of available software products, review of statistical process control and improvement literature, concept development, high-level flowcharts of the expert system [Process Improvement Expert (PI-Xpert)], development of several features of the product (alpha version of PI-Xpert), and testing of these features using KSC data. A high-level view of the software is presented in the figure. Actual KSC test data was collected and used to identify important PI-Xpert features and functions, to test the statistical algorithms in PI-Xpert, and to flowchart the application of PI-Xpert features and functions. The KSC processes that were analyzed include:

1. Structural bonding process: This process required analysis of historical data to identify a particular adhesive that was not stable and not capable. Application of PI-Xpert focused on process improvement activities to improve the function of the adhesive.

2. Potable water process: This process required monitoring nickel concentration. Application of PI-Xpert included construction of appropriate control charts.

3. Helium isolation valve leak rate process in the reaction control system: This process required monitoring of leak rates. Application of PI-Xpert included graphical depictions of data and construction of control charts.

A Phase II SBIR contract was awarded to complete the development of the expert system software, PI-Xpert. A modular approach will be used to enable PI-Xpert to perform statistical process control and improvement analyses with minimal input from users. Modules will be called by the expert system engine of PI-Xpert to perform necessary calculations. Once the PI-Xpert software is developed, training materials will be developed for KSC personnel and training workshops will be provided for interested KSC employees.

Key accomplishments:

- 1999: Review of literature addressing statistical process control and improvement applications in aviation/aerospace. Review of available expert system software and statistical process control and improvement software. Research into expert system engine design requirements for PI-Xpert. Completion of alpha version of PI-Xpert.

Key milestone:

- 2000: Development of PI-Xpert software package.

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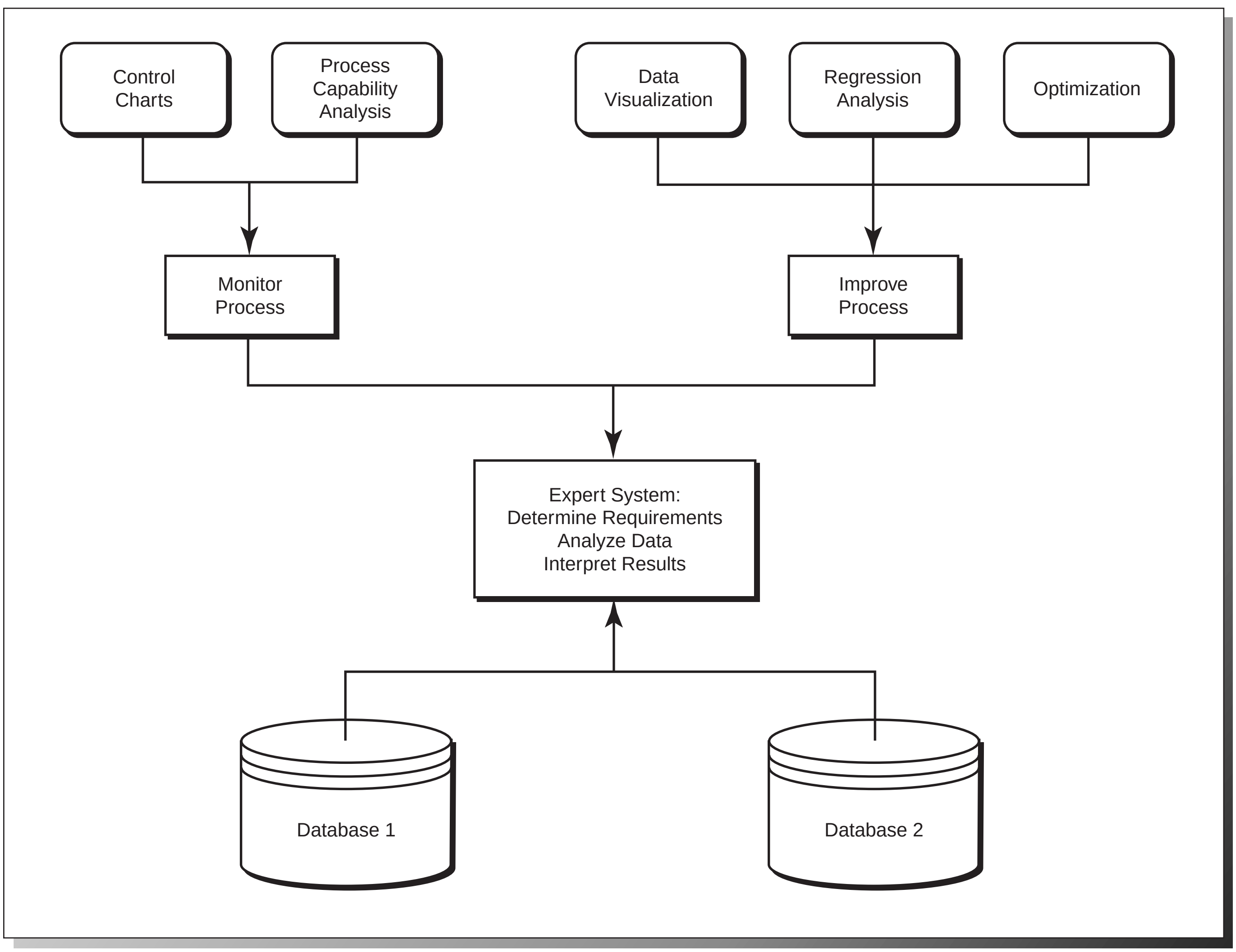
Participating Organization: Optimal Engineering Solutions, Inc. (D. Osborne, J. George, and D. Ross)



Expert System Software

Human Factors Engineering: Root-Cause Analysis System

The Root-Cause Analysis (RoCA) system helps personnel analyze and track the root causes of process anomalies due to human factors issues at the organizational, team, and individual levels. Such process anomalies include incidents that cause personnel injuries, damage facilities, incur additional costs, or delay processing. The system was developed under a Phase II Small Business Innovation Research (SBIR) contract.

The development of RoCA is motivated by the weaknesses of existing root-cause analysis techniques. Although statistical quality control methods (i.e., methods for assessing whether a process is in control) are quantitatively robust, widely used, and successful, only very simple qualitative methods (e.g., fishbone diagrams) are available for root-cause analysis (understanding why a process is not in control). The result is that industries frequently spend millions of dollars fixing the wrong process problems. The other major motivation for RoCA is the focus on the importance of human factors in industrial accidents. Research has shown that avoidable human errors are a significant source of process anomalies in many industrial processes (e.g., aircraft manufacturing and maintenance).

RoCA has many possible KSC, NASA, and commercial applications. The first application of RoCA at KSC is assisting the Human Factors Team in investigating and analyzing the contributing causes of Shuttle ground processing accidents. The major technical innovation of RoCA is the anomaly process diagram (APD). The APD is a new, theoretically well-founded methodology for root-cause analysis focused on the representation of causal, probabilistic relations between process variables.

RoCA was developed through rapid prototyping with significant design inputs from the eventual user community (i.e., the Human Factors Team). The final version includes a qualitative analysis module for graphically editing and relating the contributing factors in an event investigation through an anomaly process diagram. It also

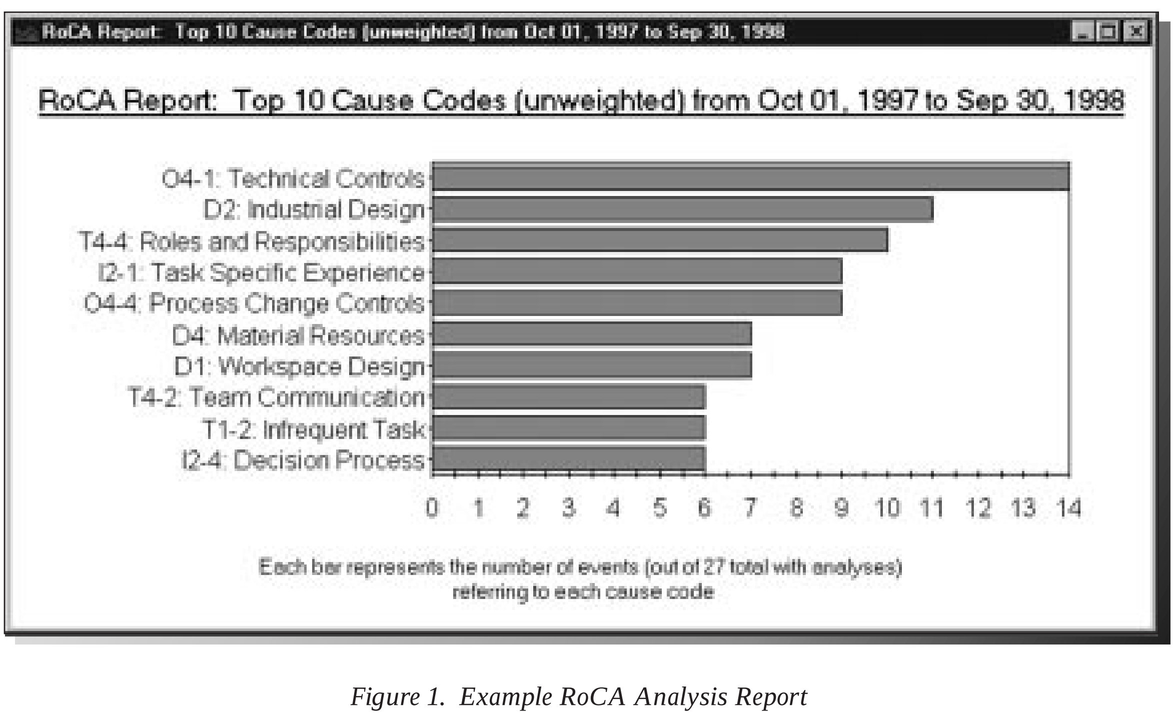


Figure 1. Example RoCA Analysis Report

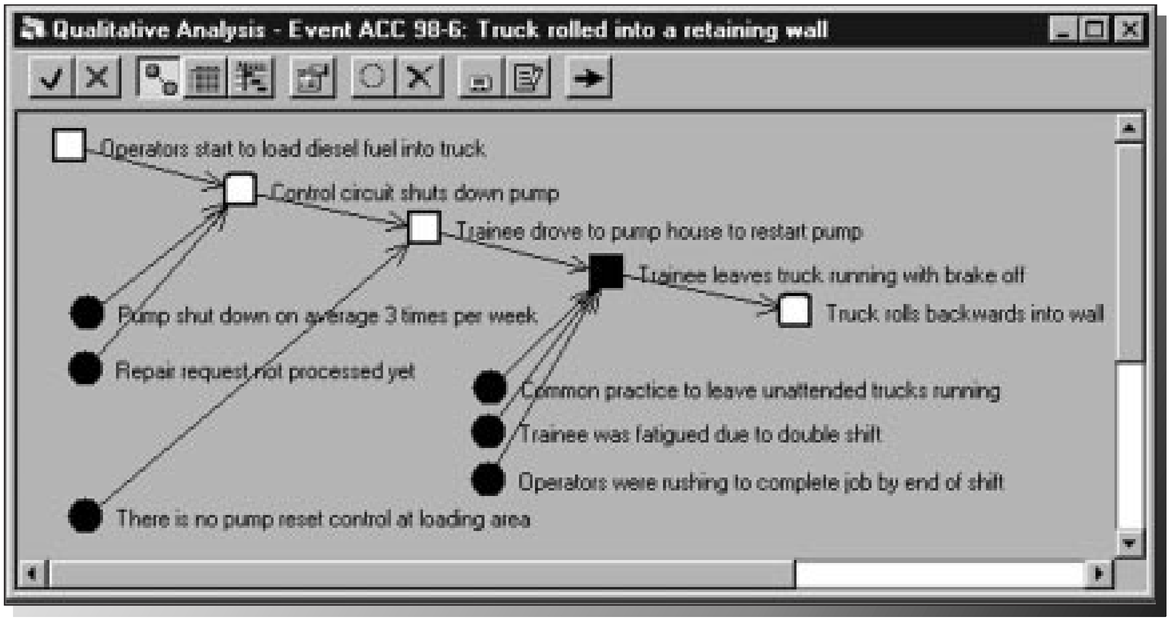


Figure 2. RoCA Analysis Display

includes a variety of predefined, standard reports the user can produce with only a few mouse clicks. These software capabilities help human factors analysts perform event analyses, communicate their analyses electronically, and understand the trends in the mishap data.

Key accomplishments:

- 1995: Phase I SBIR contract awarded.
- 1996: Completion of the Phase I feasibility study and demonstration software.
- 1997: Award of the Phase II SBIR contract. Initial software prototypes developed and delivered to KSC.
- 1998: Delivery of the first RoCA prototype system for operational use. Commercialization success of NASA-sponsored technologies through small business acquisition.
- 1999: Final delivery of the RoCA system. Distribution to KSC organizations.

Key milestone:

- 2000: Additional distribution/commercialization of RoCA and anomaly process diagram technologies.

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Participating Organizations: Fair Isaac Co. (R. Fung and B. Del Favero), United Space Alliance, NASA/Ames Research Center, and NASA/KSC (Shuttle Processing and Human Factors Integration Group)

Human Factors Engineering: Human Error Research in Shuttle Processing and Aircraft Maintenance Operations

Human error has been demonstrated to be a serious safety concern in high-risk, complex operations across a wide range of industries including aviation and space operations, nuclear power, chemical plants, and medicine among others. Although the processes in these work domains vary tremendously and, in many cases, are highly specialized and unique, they share a heavy emphasis on error-free performance, safety, and quality assurance. In addition, there is growing recognition of the importance of maintenance human factors and the need for operational research.

Past accidents have dramatically demonstrated the potential impact of human error problems in maintenance areas such as training for maintenance and inspection, tracking of maintenance responsibility, procedures and task documentation, work environment conditions, verbal and written communications, and leadership and teamwork. Although maintenance human factors is a relatively new research domain, NASA supports a maintenance-focused element in the Aviation Safety Program that is closely coordinated with the Federal Aviation Administration, airlines, repair stations, manufacturers, and other Government agencies such as the National Transportation Safety Board, Canadian Aviation Administration, and Transport Canada. Much has been gained from the sharing of lessons learned and development of collaborative research plans.

Striking similarities in human factors issues across Shuttle and aircraft maintenance have led to technology transfer meetings on topics of mutual interest. The photograph shows the Shuttle orbiter maintenance facility, which has a work environment and work processes similar to those in depot-level aircraft maintenance centers.

This Ames Research Center (ARC) and KSC joint collaboration is intended to (1) promote human factors awareness, (2) exchange research information and results, and (3) when feasible, conduct joint human factors research using KSC's unique technology testbed capabilities. Research goals focus on better understanding human error in maintenance operations in order to improve procedures, training interventions, and other maintenance task aids that will ultimately reduce human error and enhance safety in maintenance operations. These goals are being accomplished in the following ways:

1. **Technology transfer workshops**. The overall goal is to identify issues, problems, and "lessons-learned" in common interest areas across spacecraft processing and aircraft maintenance. Topics such as human error and incident analysis, risk analysis techniques, human factors training, and human performance measurement are included.

2. **Human factors research**. The goal is to combine research efforts that involve similar human factors goals and issues across multiple operational settings. For example, KSC provides a testbed for operational research in Shuttle processing while participating airlines provide an aircraft maintenance testbed. Current joint efforts include the development of human factors analysis tools for incident analysis, database development, and task/risk analysis for procedure redesign.

These efforts demonstrate an area of synergy between NASA's Aeronautics enterprise and Human Exploration and Development of Space (HEDS) enterprise. The collaboration between ARC and KSC is producing valuable results supporting the goals and objectives of both enterprises.

Space Shuttle Orbiter Entering Its Maintenance Facility

Key accomplishments:

- 1991 to 1993: Initial application of human factors technologies developed for flight crews to aircraft maintenance crews. Team effectiveness research on Shuttle maintenance crews. Memorandum of understanding between ARC and KSC signed.
- 1994 to 1995: Initial collaboration with the KSC Shuttle Processing Human Factors Team in the area of human error investigation and analysis.
- 1996: Incident Investigation Workshop hosted by ARC. This workshop focused on human factors aspects of incidents, accidents, mishaps, and close calls in spacecraft and aircraft maintenance.
- 1997: Human Factors Training Workshop hosted by KSC. This workshop focused on human factors training issues.
- 1998: Written Procedures Workshop hosted by KSC. This workshop focused on work instructions and task analysis and supported the KSC Work Instruction Task Team. Memorandum of understanding between ARC and KSC updated and signed by the Center Directors.
- 1999: Continued work supporting the KSC Work Instruction Task Team including (1) systematic comparison of three revision strategies and (2) identification of human factors issues associated with generic task functions.

Key milestones:

- 2000: Continue collaboration in incident analysis tools and task analysis. Possible workshop focusing on statistical process control applications to system performance data collected during maintenance operations.

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Participating Organizations: United Space Alliance, Transport Canada, National Transportation Safety Board, Aerospace Safety Advisory Panel, Northwest Airlines, United Airlines, Continental Airlines, U.S. Airways, Idaho National Engineering and Environmental Laboratories, and Federal Aviation Administration

Human Factors Engineering: Work Instruction Task Team

The Shuttle Processing Work Instruction Task Team (WITT) was chartered to develop and implement a comprehensive vision for future work instructions used in ground processing of the Space Shuttle fleet. The goals of the new work instruction system are to improve the efficiency of the processes used to generate and maintain the written procedures, to improve the efficiency of shop floor task execution using the new procedures, and to improve workplace safety by reducing the potential for human errors.

The team analyzed the current work instruction generation processes and products (the written procedures). Several opportunities for improvement were identified to improve the cycle time and to reduce the labor hours associated with delivering the work instructions to the shop floor to support a specific task. Existing work instructions are rule based, highly detailed, and frequently contain information not needed for a specific task. Examples of nonvalue-added information include drawings for other orbiter vehicles and work steps for testing only performed at specified intervals. The products of the work instruction process varied widely in “look and feel” for the users, which will become increasingly important as workers are more frequently assigned to different orbiter and ground systems or different facilities.

The WITT collected internal data from approximately 20 different KSC teams working on various aspects of improving the work instruction processes and external data through industry benchmarking. During 1999, the WITT efforts focused on refining the work instruction vision and implementation plan, developing tools such as document and task analysis, coordinating with stakeholders and related enhancement efforts, and removing barriers and potential barriers to vision implementation. The result of the team’s research was a vision for the future of KSC work instructions based on the following eight key elements:

- Use a standardized format for the work steps in all Shuttle processing procedures.
- Increase shop involvement in the authoring process.
- Deliver “lean, clean work instructions” with only the information needed for the current task

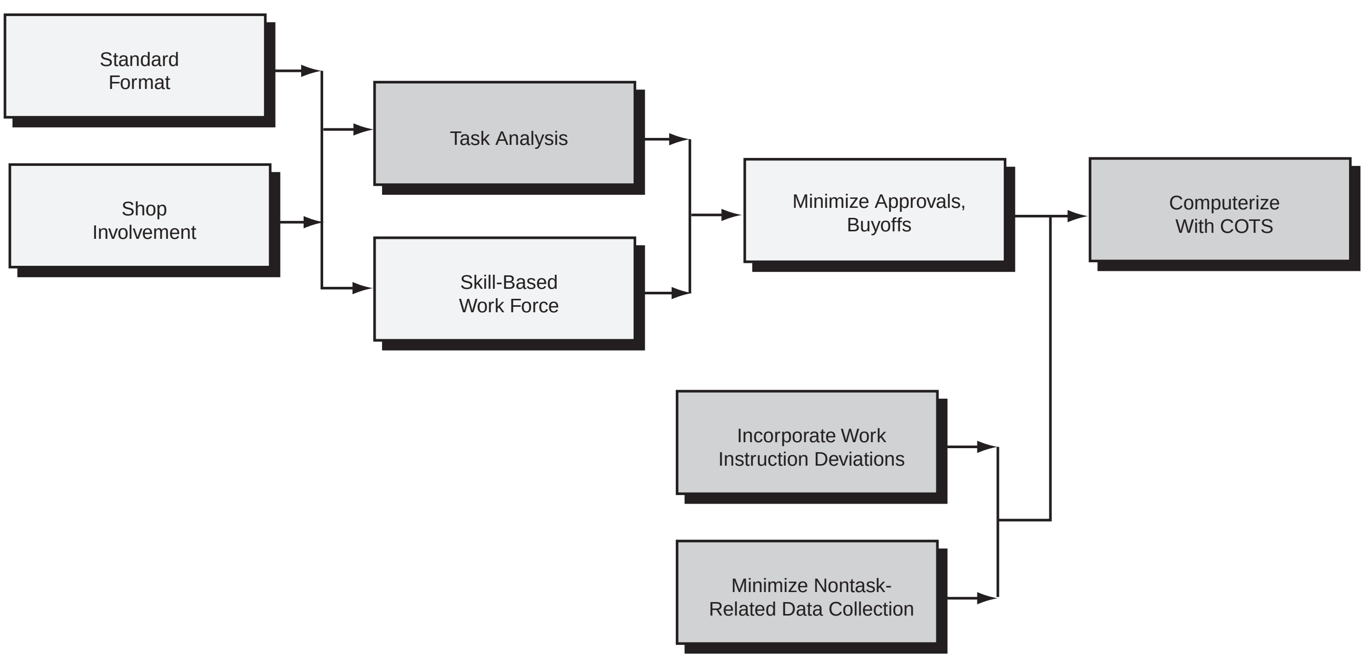

Figure 1. Key Elements of the Shuttle Processing Work Instruction Vision

and a level of detail consistent with the results of a task analysis considering task frequency and criticality/complexity.

- Take advantage of KSC's skill-based work force.

- Minimize approval, buyoff, and closure requirements.

- Incorporate all permanent, successfully executed work instruction deviations prior to release of the next revision.

- Optimize the data collection processes through innovative methods to capture nontask-related data and ensuring all data is analyzed and used.

- Use the latest commercial off-the-shelf (COTS) technologies to enhance the new work instruction process.

The recommendations directly addressed the root causes of the systemic problems associated with KSC's written procedures. The relationship between the eight vision elements is shown in figure 1. The team also constructed several conceptual models showing the relationship between task frequency/complexity/criticality to the level of detail, skill-based training, approval/buyoff requirements, and work instruction investments (see figure 2).

Key accomplishments:

- 1998: Completed the work instruction vision and obtained approval from KSC and Space Shuttle program management to begin implementation. Designed and implemented "test cases" to demonstrate the feasibility of the proposed new work instruction system. Supported a team to significantly reduce the number and complexity of the requirements for KSC work instructions. Developed a standardized format and writers guide (based on the Department of Energy's guide). Developed an initial KSC task analysis procedure. Integrated efforts with several additional teams.
- 1999: Completed a task analysis procedure. Enhanced the work instruction generation process through implementation of a distributed authoring system to provide engineers the capability to update their own documents and perform technical reviews on line. Significant enhancements to the work instruction deviation process. Writers guide and standard format template were officially approved for use in Shuttle processing. Related work instruction requirement documents were streamlined. Institutionalized WITT concepts through formation of the Vision Assurance Team. Performed initial training in WITT concepts and related software systems.

Key milestones:

- 2000: Extensive training to engineering supervisors and system engineers. Development of proactive metrics for evaluating work instruction usability. Development of enhancements to the methods for collecting data during task execution.

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Participating Organizations: United Space Alliance and NASA Shuttle Processing

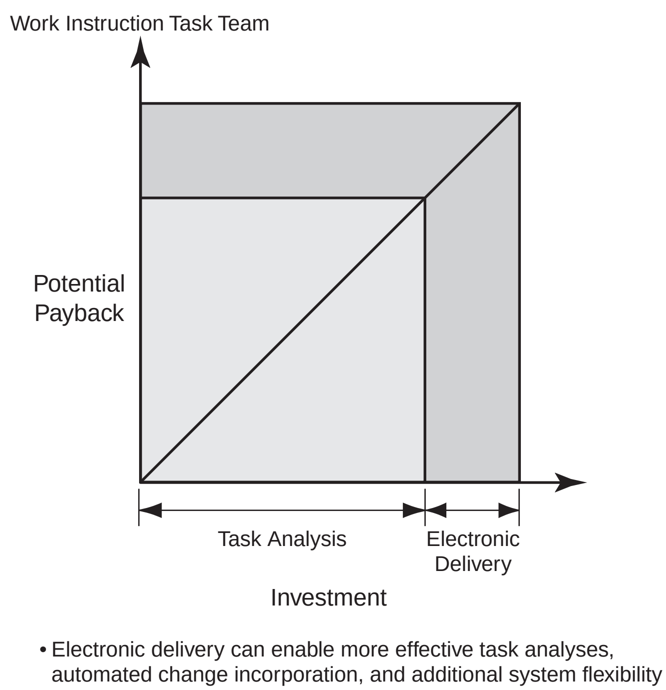

Figure 2. Work Instruction Investment Model

Work Methods and Measurement: Advanced Payload Transfer Measurement System (APTMS)

The objective of this project is to develop a simple, robust, centrally operated, and portable system to automatically measure Xo, Yo, and Zo offsets between the trunnions and their support during payload transfer operations in the Vertical Processing Facility, Orbiter Processing Facility, Operations and Checkout Building, and Payload Changeout Room. Each trunnion will be instrumented and the misalignment will be displayed to the move conductor. Future expansion capabilities include fast calculation of the next move command and closed-loop control of the operation. Key design features of the APTMS include:

- Quick Xo, Yo, and Zo measurement and display of data to the move conductor
- Small and portable transducer
- Versatile design for use at the Vertical Processing Facility, Orbiter Processing Facility, Operations and Checkout Building, and Payload Changeout Room
- Off-the-shelf optical encoders for angle measurement
- Laptop computer for ease of portable data analysis and display
- Wireless port connection between a laptop and data acquisition system
- Programming capability to calculate the next move command
- First step for payload transfer automation at the Vertical Processing Facility and Payload Changeout Room

Benefits of the APTMS include:

- Capability enhancements
- Reduction of time and cost for payload transfer
- Increase in measurement accuracy and reliability; reduction of error opportunities
- Increase in payload and technician safety
- Avenue for payload transfer automation of four different locations

Commercial applications of the APTMS include:

- Crane operations
- Construction
- Assembly
- Manufacturing
- Automotive
- Aerospace

Key accomplishments and milestones:

- Mechanical, electrical, and software system testing has been completed. Further adjustments are in work to meet the positioning requirements of 0.05 inch at a 6-inch range.
- 1995: Developed prototype unit.
- 1996: Tested prototype unit and made modifications.
- 1997: Started development of production unit, design, and fabrication.
- 1998: Completed production unit and tested and implemented modifications to enhance accuracy and ease of calibration. Developed a demonstration simulation tool for presentation to customers.
- 1999: Implemented a magnetic fixture that will attach to a steel surface to aid in the positioning of the electromechanical unit around the trunnion fixtures. Developed multiple viewing of graphical user interface as requested by the potential user.

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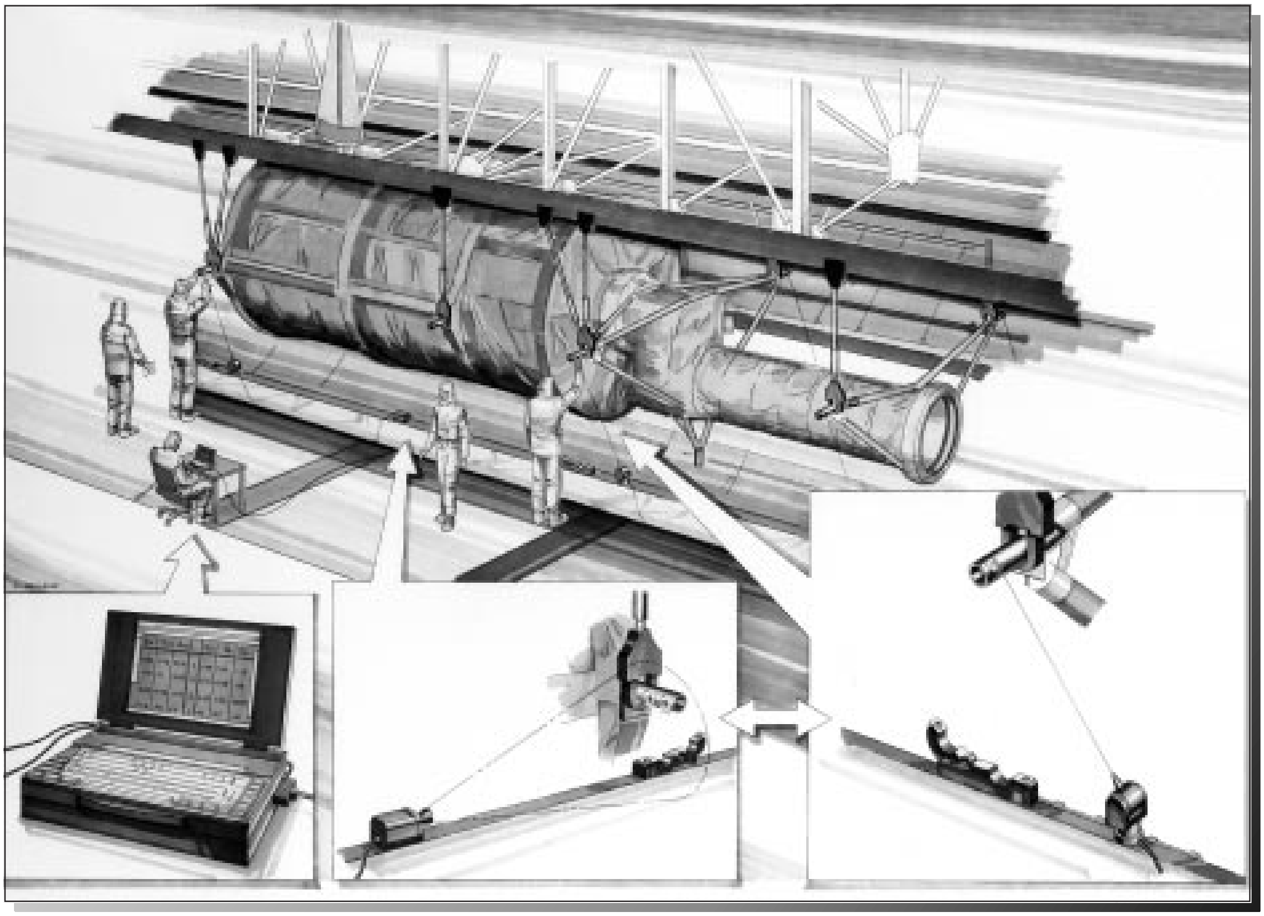

APTMS in Operation

Work Methods and Measurement: Electronic Portable Information Collection

Work procedures for payload processing and checkout operations at KSC are printed and distributed to members of the task team. The single master copy of the work procedure is kept up to date by making pen-and-ink changes to record the test data and notes. Quality and technician ink stamps are used to verify the work steps as they are performed. Test team members maintain their own copies of the procedure. Deviations to the work instructions that occur during the execution of the procedure must be documented on a paper form. These deviations require approval signatures. Once approved, the deviation is copied and distributed to the task team. The completed master work procedure, including deviations, is scanned into a computer and stored electronically.

The Electronic Portable Information Collection (EPIC) system was developed to automate this procedure. EPIC was formerly known as the Portable Data Collection (PDC) System. With the EPIC system, the procedure is converted from a word processor document to a database. It is then executed using portable computers. Data is entered electronically, either with a keyboard or a pen, using handwriting recognition. The system distributes this data to all other terminals. The ink stamp is replaced with an electronic stamp that meets the form, fit, and function of the old ink stamp. A programmable memory chip inside the electronic stamp stores a unique identifier. Every team member has an electronic stamp.

Electronic Stamp and Stamp Reader

This electronic stamp adds a secure mark to a step, identifying the person who performed that step and the date and time the step was performed. The electronic stamp is read using a stamp reader connected to the serial communication port of the computer. The system provides protection mechanisms to ensure data and stamp integrity. Once the procedure has been worked to completion, it is converted to a portable document format (PDF) and stored electronically in a documentation system.

The main components of the EPIC system are the central data server (CDS) and the portable data terminals (PDT's). The CDS is the main computer that serves as the network host and database server. PDT's display procedure steps and enable users to collect test data and stamps. The PDT's are standard personal computers (PC's) running Windows operating systems. Various PC's are used as PDT's, including desktops, laptops, wearable computers, and pen-based tablets. The CDS is a high-end PC running the Windows NT operating system.

The following benefits are provided by the EPIC system:

- All test team members see changes to the document instantly, providing greater assurance that all team members are properly informed and the data is accurate.

- Accuracy of the procedure is improved as deviations are incorporated directly into the appropriate sequence of the procedure. The time to process, approve, and distribute a deviation is also reduced.

- Information availability is improved. Test data can be searched and retrieved through a standard database.

Team Members Using EPIC

- Queries can be made for management reporting or incident investigations.
- The need to print and distribute procedures prior to testing is eliminated.
- The need to scan the procedure for storage is eliminated.
- Emergency procedures can be accessed immediately.
- Paper usage is reduced.

The project was developed jointly by SENTEL Corporation and KSC, the lead center for payload processing. The prototype system was developed under a Small Business Innovation Research (SBIR) contract that was awarded to SENTEL Corporation to develop the capability to capture technician and quality stamps and test data electronically. The operational version was developed under a Space Act Agreement between NASA and SENTEL Corporation.

EPIC is being tested for use in the NASA Payloads Logistics Depot, which provides centralized manufacturing and maintenance for flight hardware and ground support equipment. A large residential construction company is currently using EPIC for inspection on construction sites. SENTEL is also actively marketing EPIC to other private industry, including the aerospace industry.

Key accomplishments:

- 1993: Completed the Phase I study for the SBIR contract.
- 1996: Completed Phase II of the SBIR contract. Demonstrated the proof of concept for this system. Received the NASA SBIR Technology of the Year Award in the computer/software category. The first pilot study was conducted in the Operations and Checkout Facility.
- 1998: Upgraded the system from a prototype to an operational system. Pilot studies of the EPIC system were conducted in the KSC Space Shuttle Main Engine Shop and the Space Station Processing Facility.
- 1999: EPIC was first used by a private residential construction company for site inspections. Testing was conducted in the NASA Payload Logistics Depot.

Key milestone:

- 2000: Implement the EPIC system to be used by NASA, Government contractors, and private industry.

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Participating Organizations: SENTEL Corporation (C. Bonnette)

Work Methods and Measurement: Solid Rocket Motor (SRM) Stacking Enhancement Tool (SSET)

The NASA Automated Ground Support Systems Laboratory (MM-G3) of the Engineering Development Directorate is developing the SSET, a mobile data acquisition system used to monitor the Space Shuttle SRM stacking process in the Vehicle Assembly Building at KSC. Four SRM segments are mated together to form a solid rocket booster with two completed boosters used for each Space Shuttle. SRM segments are attached to a four-point lifting beam, a device that can vary the load of each of its attachment points and modify the segment shape to match that of its partner. The entire assembly is then hoisted by a crane and lowered onto the SRB under construction. The segment junction points, or field joints, are critical interconnections whose failure could cause a catastrophe.

The stacking process takes many hours and is labor intensive; so delays due to system failures are costly. The SSET replaces and combines the functions of two antiquated systems already in use, the Temposonics measurement system and the lifting beam load panel. The Temposonics measurement system is composed of four one-dimensional sensors (which are located at 90-degree intervals between the two segments) and a data acquisition computer system (used to display and record the numerical measurements). The measurements are used to determine the distance to mate, the levelness, and the lowering rate. The lifting beam load panel uses six strain-gage-type load cells located in the SRM lifting beam to measure the loads and levelness forces of the suspended segment. Currently, no data recording is available for the loads.

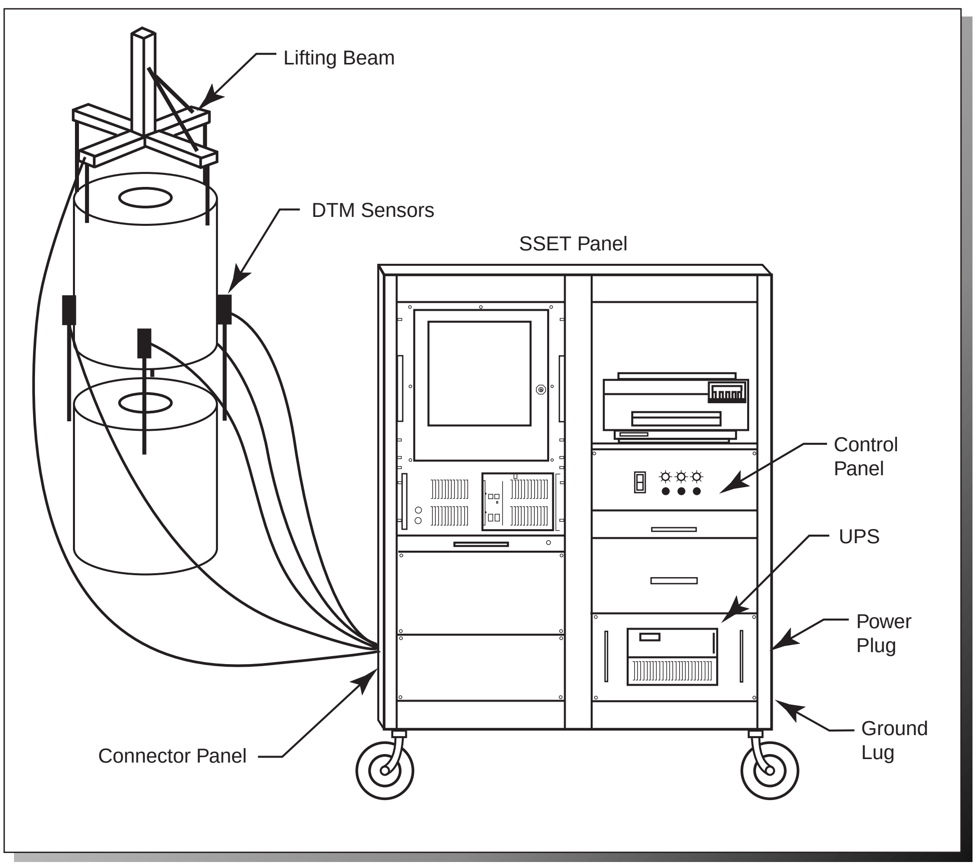

Figure 1. SRM Stacking Enhancement Tool

The SSET provides current technology data acquisition equipment to measure the existing sensors. Some benefits of the SSET are:

- A single display unit reduces the number of equipment items (figure 1).
- The information is displayed on an intuitive graphical user interface and is easy to interpret (figure 2).
- All measurement data is recorded.

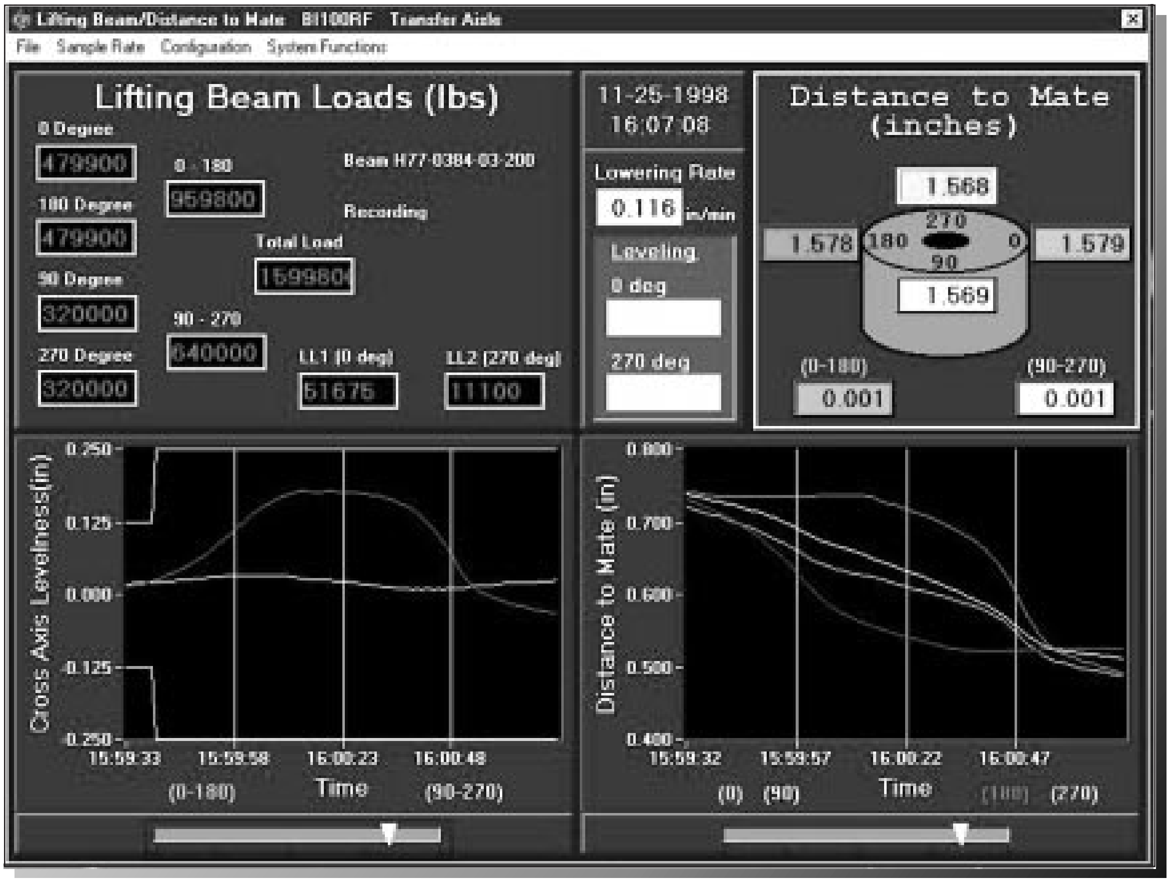

Figure 2. Graphical User Interface

- The modular design allows system modifications and updates.
- The onboard uninterruptible power supply (UPS) guards against data loss due to power failure.
- Advisory functions help operators maintain segment levelness.
- Built-in test ports allow for easy troubleshooting.
- All operator events and configuration values are logged for future reference.
- Up to 1 hour of real-time data is maintained for review during stacking.
- Data review software is provided for posttest analysis.

Key accomplishment:

- 1999: Transferred the SSET to operations for SRM Shuttle stacking.

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Participating Organizations: Dynacs Engineering Co., Inc.; NASA PK-H; and United Space Alliance

Work Methods and Measurement: Automation of OMI S9002 for Orbiter Processing

Information availability to make critical Space Shuttle orbiter launch readiness decisions has just gotten easier and quicker. Thanks to a new application that automates data collection, distribution, and signoff of operations and maintenance instructions (OMI's), engineers can perform a Posttest Data Review as easily as using a Web browser from any networked computer at KSC. The information reviewed consists of sensor data collected during critical processing of orbiters from the time an orbiter lands up to and including the next launch. OMI S9002 consists of subordinate OMI's, including S0007, the OMI for orbiter launch. S0007 includes creation of roughly 2,500 data products containing sensor readings and is initially targeted for automation of S9002. These data products require review by engineers responsible for each orbiter subsystem (e.g., avionics, flight controls, main engines, hazardous gas systems, auxiliary power units, etc.).

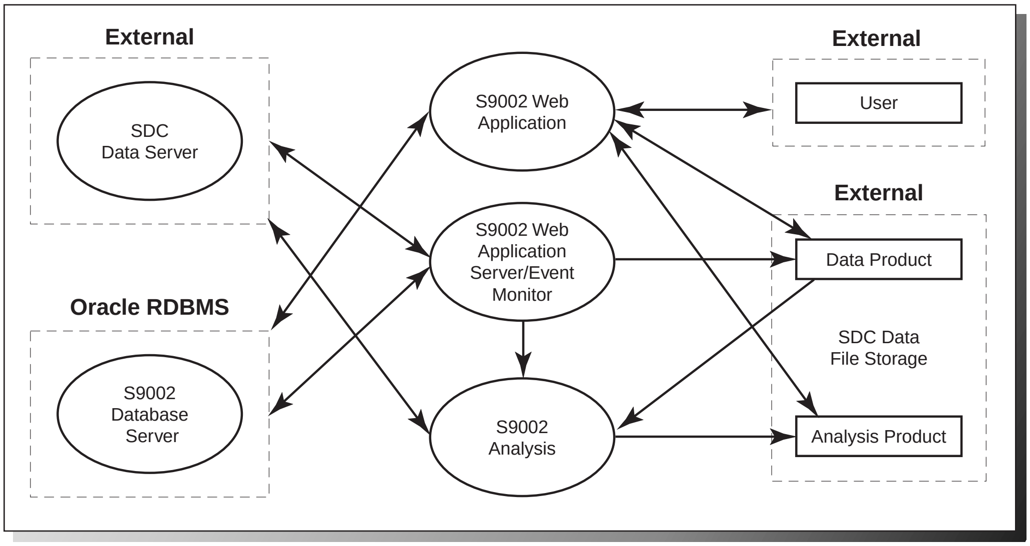
Data products traditionally consist of hard-copy printouts in the form of graphs or tabular listings of periodic sensor readings usually specified to include a start event and stop event. Some data products are run on request for subsystem engineers (typically in the firing room). These data products are termed "will calls."

The previous S0007 of S9002 process includes the following manual steps. First, Data Review Room (DRR) personnel manually monitor launch processes for specific data product start and stop events. After certain stop events occur (which may be hours or days following a start event), DRR personnel log into the central data system (CDS). Next, DRR personnel request a specific data product to be run and specify the printer or plotter for the hard-copy printout. Then the hard copy is either picked up or hand carried to the engineer (will calls). The responsible engineer reviews the physical data product, analyzes the data for potential problems, and determines the health of the subsystem (analysis of large listings may take hours). Last, engineers return to the DRR to buy off data products for which they are responsible (from 1 to 300 data products per subsystem).

The original goals of the S9002 automation project were (1) to automate the event-based generation of greater than 80 percent of data products for OMI S0007 [with emphasis on hazardous gas (HAZGAS)]; (2) to enable workflow processes to display, review, and sign off data products by responsible engineers from desktop computers using the World Wide Web; and (3) to investigate use of available commercial off-the-shelf (COTS) expert system products and/or technologies to assist responsible engineers with analysis of data products.

To implement Automation of S9002 cost effectively, use of COTS systems, development tools, and a database were utilized. The S9002 database was modeled, designed, and implemented using a full-function Relational Database Management System (Oracle 7 RDBMS) and a Web application server (Oracle Application Server). Software was written to automatically load the database from legacy system sources that included a DRR Dbase IV, CDS formatted files, CDS transaction files, and CDS FD files. Listeners and agents were integrated into the database server to enable transparent interfaces to all other S9002 subsystems, whether local or remote.

An event monitor, designed and implemented using the Java language, monitors the occurrence of start and stop events and interfaces with both the Shuttle Data Center (SDC) and S9002 databases. An application server module, also developed using



System Architecture Overview

Java, communicates with the event monitor, SDC, analysis module, and S9002 database to handle the scheduling and control of data product creation, transfer to the database server, and triggering of data product analysis. In parallel, the programs that actually produce data products (DAP's and CAP's) were migrated from the CDS to the SDC and modified to enable file as well as hardcopy output. These programs underwent significant code modification and testing to ensure standardization of inputs, execution options, and functionality.

Another effort associated with Automation of S9002 developed an analysis module. A decision was made to create a rule-based expert system application module that would perform the same steps as an engineer when analyzing a large collection of HAZGAS sensor data. A complete set of rules was established for several large data sets by interviewing the engineers and documenting their thought processes. These rules were then organized into a Java application class, and methods were written to enable reducing the analysis to a single page output describing any anomalies found. If anomalies exist, a brief explanation of each is included in the analysis output along with violated parametrics.

Completing the system required a user interface module. This module needed to run on platform-independent desktop computers (Windows, Macintosh, and UNIX workstations), with the only requirement being a commercially available Web browser. The PL/SQL language was used for dynamic creation of Hypertext Markup Language (HTML) sent to/from the client platform. This approach yielded a highly responsive, easy-to-code-and-use interface with dynamic screen sizing.

Results of Automation of S9002 to date have exceeded the original requirements. As a result, greater than 95 percent of data products for S0007 (orbiter launch) run automatically and are available for viewing within 30 seconds after stop events occur. The S9002 database and application software support all S9002 OMI's (approximately 5,300 data products). Engineers can run standard and custom data products for execution immediately. Several Space Transportation System flows (orbiter processing, launch, etc.) can run simultaneously. Rule-based analysis of large volumes of data for HAZGAS has proven very efficient and identified in near real time many interesting anomalies (gas leaks, power supply outages, sensor failures, etc.) hours before discovery by responsible engineers using manual methods. The engineers now have a tool to monitor subsystem health, review discovered anomalies, and electronically sign off completed data products without leaving their desks. These savings in engineering and data support personnel time will result in better, cheaper, and faster decisions when it comes to the safety and success of launch operations at KSC.

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Participating Organizations: Dynacs Engineering Co., Inc. (W. Spiker, II; J.M. Dockendorf; and J. Zambrano), United Space Alliance (W.S. Bayles), and Boeing (D.J. Cox)

Work Methods and Measurement: Circularity Measurement Tool (CMT)

The current sine bar system used to measure the circularity of the solid rocket motor (SRM) segments is obsolete and replacement parts are difficult or impossible to find. Sine bar sensors are of an insufficient range for accurate modeling of some SRM segments. United Space Alliance has identified the existing system as a potential candidate for the year 2000 computer glitch. The shape prediction program, which uses the sine bar measurement data to recommend parameters used to shape the SRM segment, is located on a remote computer, causing processing delays. The sine bar tool that hangs from the operator's neck is heavy, posing a potential health risk. The technical approach to this problem is to upgrade the existing design as follows:

1. Replace the sensors and signal conditioning devices on the sine bar tool with current technology sensors and a microcontroller to digitize and transmit the measurement data.

2. Replace the data display computer with an industrial computer based on current technology.

3. Incorporate the shape prediction program into the new system.

4. Replace the existing sine bar tool harness with an ergonomic one.

Current technology computers and sensors will alleviate the obsolescence problem and eliminate the year 2000 glitch, preserving the Space Shuttle manifest. Larger ranged sensors will allow all SRM segments to be more accurately modeled and reduce the number of shaping iterations. Digitizing the sensor data before transmitting it to the data display computer will improve signal quality and reliability. Incorporation of the shape prediction program will significantly reduce the SRM stacking time. The new tool design will be lighter than the previous one and will use a comfortable harness, reducing the risk to operators.

Key milestones:

- Developed and tested laser-sensing CMT for SRM circularity measurement.

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Participating Organizations: Dynacs Engineering Co., Inc.; NASA PK-H; and United Space Alliance

General Industrial Engineering: Center for Applied Research in Industrial and Systems Engineering

A partnership between NASA and Florida International University (FIU) has created the Applied Research in Industrial and Systems Engineering (ARISE) Center. The mission of this partnership is to establish a long-term, self-sustainable combined research and educational program to attract and retain women, Hispanics, African Americans, and other underrepresented minorities to engineering and NASA-related career paths. The goals of the ARISE Center are to provide students with opportunities to apply the concepts learned in the classroom to real world projects, to investigate issues for industry practitioners and/or academicians, and to be ready to fully participate as members of the diverse workforce of the 21st century. Since establishment of the Center, several companies have also partnered with FIU in this endeavor.

Participating students are assigned projects with a KSC or industry representative serving as project manager. Projects vary in topic and length of duration. Past projects include Space Utilization in Facilities Planning, Work Area Ergonomic Study, Basic Inventory Decision System, and Business Plan for a Sub-Orbital Space Ride. Students are exposed to NASA's mission; are given seminars on a multitude of topics including workplace, gender, and diversity issues; are advised of the benefits of and encouraged to pursue postgraduate studies; have a 4-week internship at KSC; and receive a stipend during the academic year. Students also attend to their regular curriculum during the academic year.

Key accomplishments:

• 1997:
- Established a research center. Selected and purchased hardware and software for the center.
- Recruited students, developed a brochure, and developed a Web page (http://arisecenter.eng.fiu.edu/).

• 1998:
- Conducted seminars, including an overview of NASA and issues on gender and racism in the workplace.
- Students participated in internships at KSC.
- Completed five projects; gave technical elective course credit for projects.
- Provided a statistical analysis workshop for KSC personnel.
- Prepared a proposal to attract industry to this effort.

• 1999:
- Upgraded hardware and software for the Center.
- Completed five projects, gave technical elective course credit for projects.
- Showcased projects at an industry seminar.
- Recruited industry partners.

Key milestones:

• 2000:
- Identify additional projects in January.
- Recruit additional industry partners.
- Provide summer internships for students.

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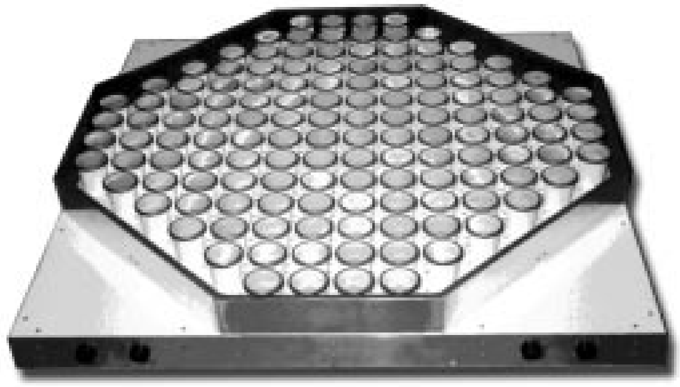
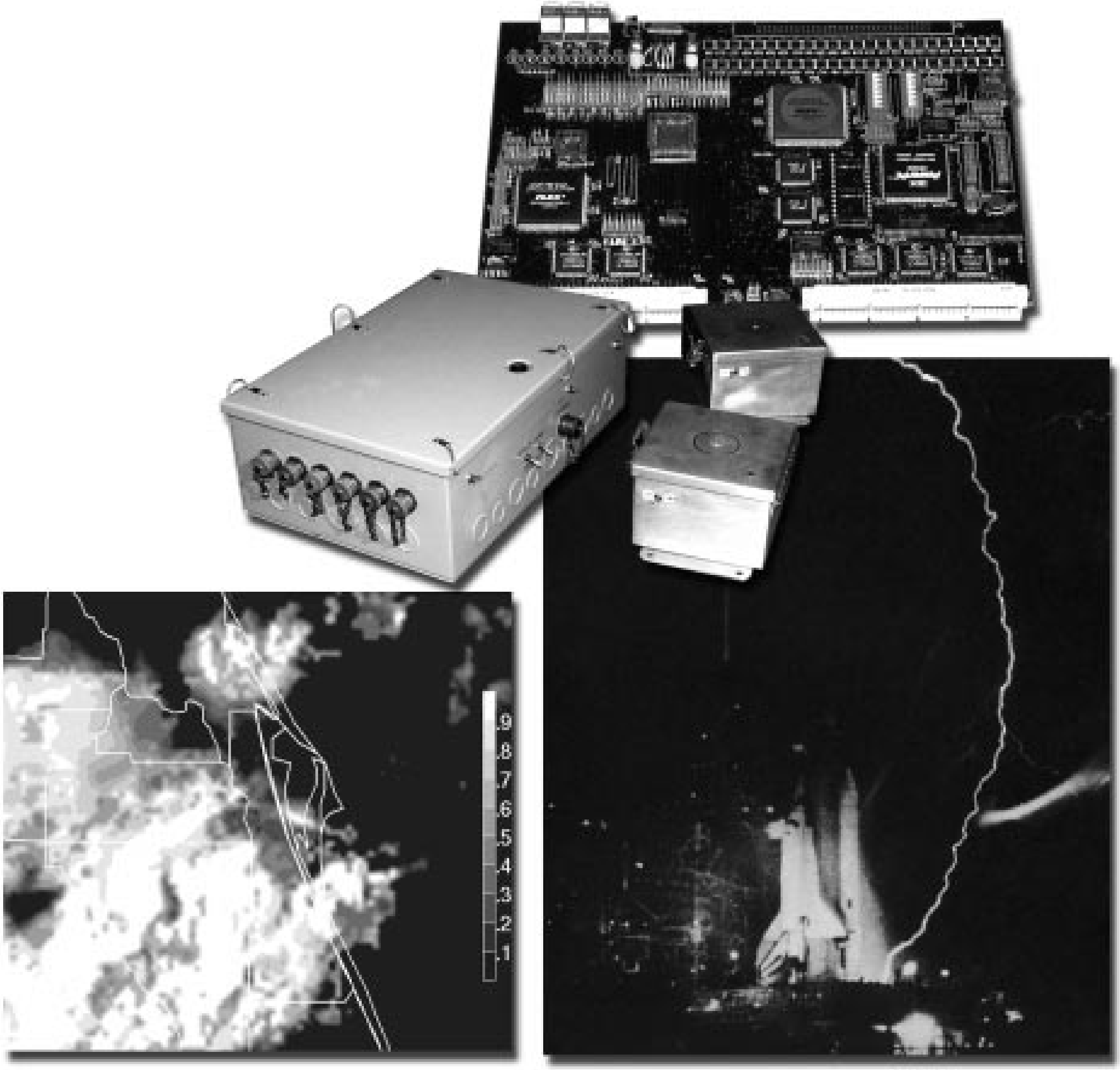
Participating Organization: Florida International University (M. Centeno)



Range Technologies



HyperSodar

In response to NASA's need for a remote wind sensor system capable of wind profiling at spatial scales of 10 meters and time scales of an order of 1 second with a measurement accuracy of a few tenths of a meter per second in speed and a few degrees in direction, a new and promising technology in high-resolution remote wind measurements, HyperSodar, has been successfully developed during the Small Business Innovation Research (SBIR) Phase I and II program with NASA at KSC.

HyperSodar is an active acoustic phased array antenna system designed to significantly increase the spatial and temporal resolution of measurement by simultaneously measuring multiple sets of three orthogonal components of a three-dimensional wind field on a single transmission pulse. This task is accomplished by transmitting a broad-beam acoustic pulse to illuminate a zone of the atmosphere and then measuring Doppler shifts in backscatter signals arriving at the system from various directions along the broad-beam projection utilizing simultaneous receiving beams of a narrow beamwidth. The simultaneous beams are obtained by means of a hybrid of analog and digital beam-forming technologies that enables simultaneous forming of a programmable number of receiving beams in any-look directions within the designed fields of view. HyperSodar employs a novel spectral processing technique, co-spectrum method, for Doppler processing. The co-spectrum method induces a cancellation of incoherent noise components in the backscatter signals to significantly increase the signal-to-noise ratio enabling accurate wind measurements on a single transmission pulse, thus dismissing the need for time-consuming incoherent spectral averaging.

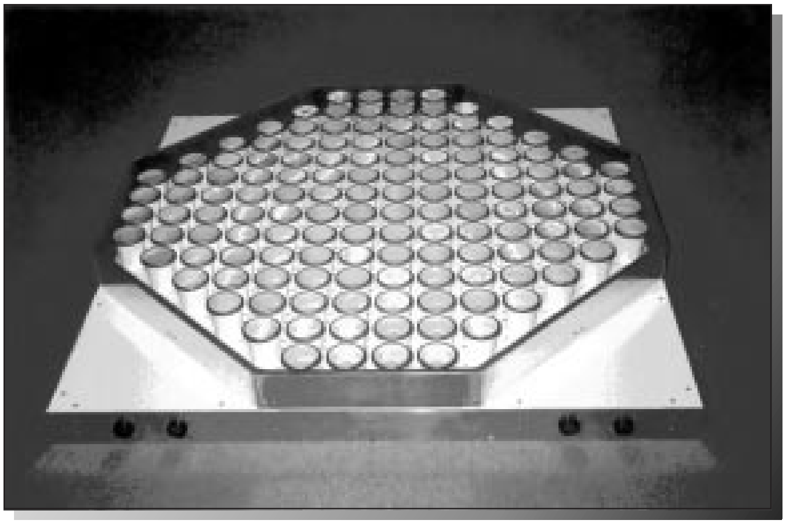
Electronic Cabinet of the Prototype HyperSodar System

Key accomplishments:

- 1996: Successful completion of the HyperSodar feasibility study under the SBIR Phase I.
- 1997: Development of a prototype HyperSodar system under the SBIR Phase II.
- 1998: Progressed in the development of the prototype HyperSodar system.
- 1999: Successful completion of the prototype HyperSodar system (see the photographs), extensive field tests and performance evaluation, and completion of the HyperSodar utility patent application filing with the U.S. Patent and Trade Office.

Key milestones:

- 2000: Development of the HyperSodar system for commercial and NASA applications with emphasis on wind profiling in the vertical mode.
- 2001: Development of the HyperSodar system for commercial and NASA applications with emphasis on wind profiling in the lateral mode.
- 2002: Development of a long-range (more than 1.5 kilometers) HyperSodar capable of simultaneous vertical and lateral mode operation for commercial and NASA applications.



Acoustic Phased Array Antenna of the Prototype System

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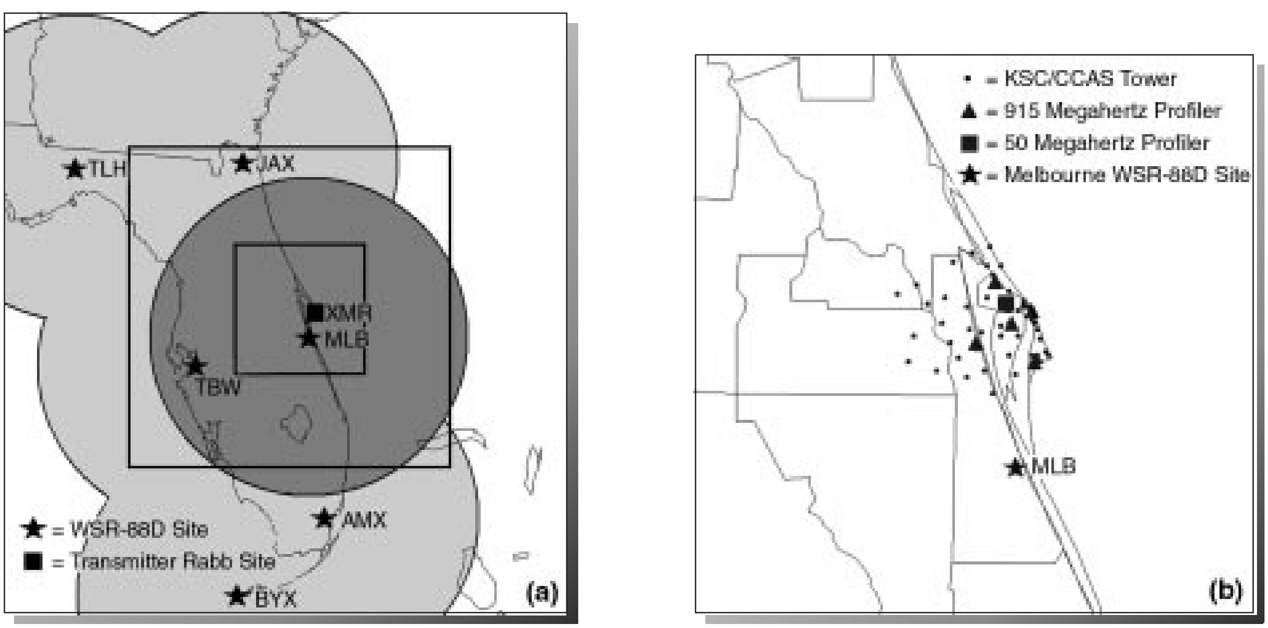
Participating Organization: Sensor Technology Research, Inc. (P. Chintawongvanich)

Configuration of a Local Data Integration System Over East-Central Florida

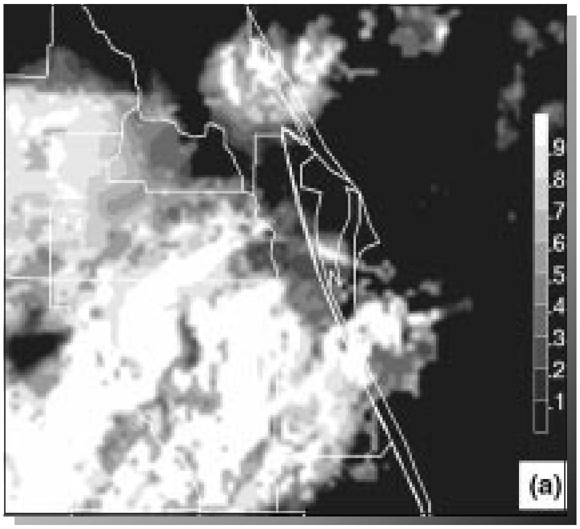
The recent development and implementation of many new in situ and remotely sensed observations have resulted in a wealth of meteorological data for weather forecasters. However, the complexity of short-term forecasts has increased due to the variety and differing characteristics of the multitude of available observations. Tools are required to integrate and assimilate data into a single system in order to simplify the interpretation of the atmosphere while retaining the capabilities of new data sources. Therefore, the objective of this project is to configure a Local Data Integration System (LDIS) over East-Central Florida that can integrate all operationally available meteorological observations at high-temporal and spatial resolutions. The ultimate goal for running an LDIS is to generate products that can enhance weather nowcasts and short-range forecasts issued in support of operational requirements at the 45th Weather Squadron, Spaceflight Meteorology Group (SMG) at the Johnson Space Center, and Melbourne National Weather Service.

The Applied Meteorology Unit simulated a real-time configuration of the LDIS over the Florida Peninsula including KSC and Cape Canaveral Air Station (CCAS) using a 2-week data set archived at SMG. The LDIS consists of analysis and display software that integrates observational data onto a series of three-dimensional grids and provides meteorological analyses at high-temporal and spatial resolution. In combination with suitable visualization tools, the LDIS can provide users with a more complete and comprehensive understanding of evolving fine-scale weather features than could be developed by individually examining the dispa-

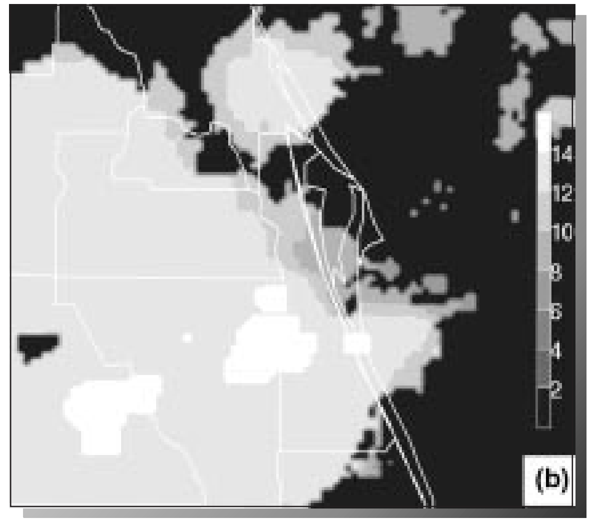


Florida Peninsula *East-Central Florida*

Figure 1. Distribution of Doppler Radar Data (WSR-88D) and KSC/CCAS Observations in the Simulated Real-Time LDIS Configuration (Coverage of radar data across Florida is given by the shaded regions.)



Cloud Fraction



Cloud-Top Heights

Figure 2. LDIS High-Resolution Cloud Products (Progressively brighter gray shades represent an increase in 10 percent cloud cover in (a) and progressively brighter gray shades represent an increase in cloud-top heights by 2 kilometers in (b) with the brightest shade more than 14 kilometers.)

rate data sets over the same area and time.

The LDIS demonstrated utility in:

- Depicting high-resolution quantitative characteristics of cloud fields such as ceilings, cloud-top heights, cloud liquid content, cloud ice content, and fractional cloud cover.
- Monitoring and diagnosing wind characteristics including a sea-breeze passage at the KSC Shuttle Landing Facility.
- Assessing atmospheric stability indices at high resolutions to determine thunderstorm risks.

Figure 1 depicts the type and spatial distribution of data that were ingested into the simulated real-time LDIS. Figure 2 demonstrates the high-resolution cloud products that are available in the LDIS, including cloud fractions (figure 2a) and cloud-top heights (figure 2b).

Key accomplishments:

- 1997 to 1998: Configured an LDIS specifically for East-Central Florida, tailored to the operational needs of KSC and CCAS.
- 1998: Illustrated the fidelity and utility of the system by examining a warm-season case study of thunderstorms and strong winds that caused scrubbing an Atlas mission, and a cool-season case study of a cold-frontal passage and its associated clouds and precipitation.
- 1999: Simulated a real-time configuration of the LDIS using operationally available data archived at SMG.

Key milestone:

- 2000: Installation of an operational LDIS at SMG and Melbourne National Weather Service.

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Participating Organization: ENSCO, Inc., (J.L. Case)

Single-Station Accurate Location of Lightning Strikes

The objective of this project was to design an accurate single-station lightning location system to aid in the detection of lightning strikes within the Space Shuttle launch pad perimeter. Existing lightning location systems at KSC provide coverage of a wide area extending over a 30-mile radius but have an accuracy on the order of about 500 meters within the KSC area. These systems cannot be used to determine, for instance, whether a lightning strike occurred inside or outside the perimeter of the launch pads. Existing systems cannot tell whether a pad structure was hit by lightning unless a camera just happens to record the strike. However, if the cameras are not pointing in the correct direction or if their field of view is obscured by either the pad structure or a heavy downpour, the determination of the striking point becomes difficult. Since electronic equipment can be damaged by the effects of nearby lightning strikes, the accurate knowledge of the striking point is important for determining which equipment or system needs to be retested following a lightning strike.

The fast-varying electric currents associated with lightning strikes generate large electric field variations. The electric field waveform propagates at the speed of light in a radial direction away from the striking point. The sudden heating of the air caused by the large currents associated with the lightning discharge produces a sudden expansion of the air near the lightning channel. This results in a sonic wave (thunder) that initially, for the first few meters, propagates at a supersonic speed and later propagates at a sonic speed. For an observer located away from the striking point, the electric field waveform arrives earlier since it travels at a speed of 300,000,000 meters per second (m/s), while the sonic wave travels only at about 340 to 360 m/s. For a given location, the variation in the speed of sound is caused mainly by the temperature of the air and, to a lesser extent, by the moisture content. The observer can determine the distance to the striking point by measuring the time between the arrival of the electric field waveform and the arrival of the sonic wave.

The improved lightning location system consists of an electric field sensor and five sonic (thunder) recorders. Four of these sonic sensors are located in the perimeter of a 5-meter radius circle, 90 degrees apart from each other, with the electric field sensor placed in the center of the circle. The fifth sonic sensor is located 2 meters above the plane formed by the four sensors. Following a lightning strike, the sonic wave arrives at each sensor within milliseconds of each other, since the distance to the striking point is slightly different for each sonic sensor. Based on the differences in the time of arrival of the sonic wave at each sensor, a set of equations can be solved to determine the angle of arrival of the sonic waveform. The differences in the time of arrival can be pre-

cisely measured, to better than 10 microseconds, by performing real-time digital cross-correlations among the signals received by the five sensors. The distance to the lightning strike is determined by the time elapsed from the detection of the electric field to the detection of the thunder signal.

Digital signal processing techniques are used to discriminate between thunder waveforms from a close lightning strike (within about a 1-mile radius) and thunder waveform from a preceding distant strike. This process is important since during the active phase of a thunderstorm lightning activity could occur at a rate exceeding 10 strikes per minute.

Key accomplishments:

- Prototyped and tested the electric field sensor, the sonic sensors, and the microprocessor-based controller. The testing was done with both natural and triggered lightning.
- Developed and tested an algorithm to combine the information received from a network of sensors to determine the angle of arrival of the thunder signal.

Key milestones:

- Install the sonic lightning locator at the launch pads.
- Evaluate the performance of the system and refine the algorithms if needed.

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Participating Organization: Dynacs Engineering Co., Inc. (P.J. Medelius, J.S. Moerk, J.D. Taylor, and J.J. Henderson)

Automated Calibration Station for Universal Signal Conditioning Amplifiers (USCA's)

The goal of this project was to design a fully automated calibration station for USCA's. A USCA is a self-configuring amplifier designed to interface with a variety of transducers. Parameters such as gain, excitation voltage, sampling rate, and filtering are automatically set based on information stored in a small memory device attached to the transducer. The data on the Transducer Electronic Data Sheet (TEDS) is read by a USCA immediately after the connection to the transducer is detected. Highly stable reference voltages, resistive dividers, and current-sensing resistors are used to ensure long-term stability. A USCA is designed to perform continuous self-calibration, based on the reference parameters stored in its nonvolatile memory. Calibration factors stored in a USCA's memory are used to ensure the accuracy of a measurement is maintained within specifications, even when the USCA is subject to large temperature variations.

Following the manufacturing process, a USCA has to be fully calibrated before deployment in the field. A periodic calibration every 1 or 2 years is also required to confirm a USCA is operating within its specifications. The calibration procedure must be repeated following any maintenance work or repair on a USCA. The calibration process includes measuring the reference voltages a USCA uses for its self-calibration, measuring the precision resistors used for current measurements and current excitation, correcting for offsets, and others. The process takes about 30 minutes to complete when conducted by an experienced technician.

A USCA requires certain parameters to be stored in its nonvolatile memory in order to perform its continuous self-calibration. These parameters include three reference voltages, zero offsets, current sensing resistor values, excitation resistor divider ratios, and input voltage resistor divider ratios. The calibration station was designed using a combination of custom-developed software in the USCA and a Test Point based program running on a personal computer. The Test Point program is used in conjunction with an external voltage/current source and an accurate, NIST-traceable voltmeter to fully automate the calibration process. The automated calibration station can generate a calibration data sheet if requested.

The calibration process takes about 15 minutes under computer control. The involvement of a technician in the calibration process is limited to connecting a USCA, pressing the start button, and disconnecting the USCA after the calibration is complete.

Key accomplishments:

- Completed the design and assembly of the automated calibration station.
- Developed and tested a method to fully calibrate a USCA without the need to remove it from its sealed enclosure.

Key milestone:

- Delivery of the automated calibration station.

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Smart Troubleshooting Station for Universal Signal Conditioning Amplifiers (USCA's)

The goal of this project is to design a smart troubleshooting station for USCA's. A USCA is a self-configuring amplifier designed to interface with a variety of transducers and consists of three main sections: analog, digital, and power. Over 800 components, both passive and active, are used in each USCA. Occasional failures of a USCA can occur as a result of a defective component on any of the three sections. With almost 1,000 USCA's soon to be in service, significant repair time can be saved by the use of an automated troubleshooting station.

USCA's have the capability to communicate with a computer and to receive commands that override the settings specified by the information stored in the Transducer Electronic Data Sheet (TEDS) . The TEDS is a small memory device that is attached to every transducer connected to a USCA. The TEDS contains information that a USCA uses to configure itself to operate with a particular transducer. This information includes transducer excitation voltage, current, gain, filtering requirements, input/output range, and others.

There are failure modes that will render a USCA completely inoperative. Fatal failures can be caused by a blown fuse, a faulty microprocessor, or lack of power on the digital section. Also, there are failures that will affect only certain functions of the USCA, while other functions continue to operate properly. The troubleshooting station is being designed to identify the section of a USCA where a problem has occurred, whether fatal or partial, and to provide a list of components to be checked by the technician.

The smart troubleshooting station will use a combination of custom-developed software in the USCA and a Test Point based program running on a personal computer. The Test Point program is used in conjunction with external voltage/current source, accurate multimeter, and interface circuit.

The troubleshooting station will command a USCA to perform internal diagnostics, depending on the failure being observed. The station will also control the voltage/current source to apply the appropriate signals to the USCA under test. These tests are similar to those a technician would have to perform if the operation were being done manually. Based on the results of the initial tests, the troubleshooting station will try to identify the component or components most likely to be the cause of the observed failure. The troubleshooting station can request the technician to take voltage or oscilloscope measurements on a USCA board and to report the results. The troubleshooting station then analyzes the results, determines whether additional tests are necessary, and requests a new measurement. Once the problem has been isolated, the troubleshooting station will determine which component or components should be replaced.

Key accomplishment:

- Started the design of the automated troubleshooting station.

Key milestone:

- Evaluate the performance of the automated troubleshooting station and refine the software if needed.

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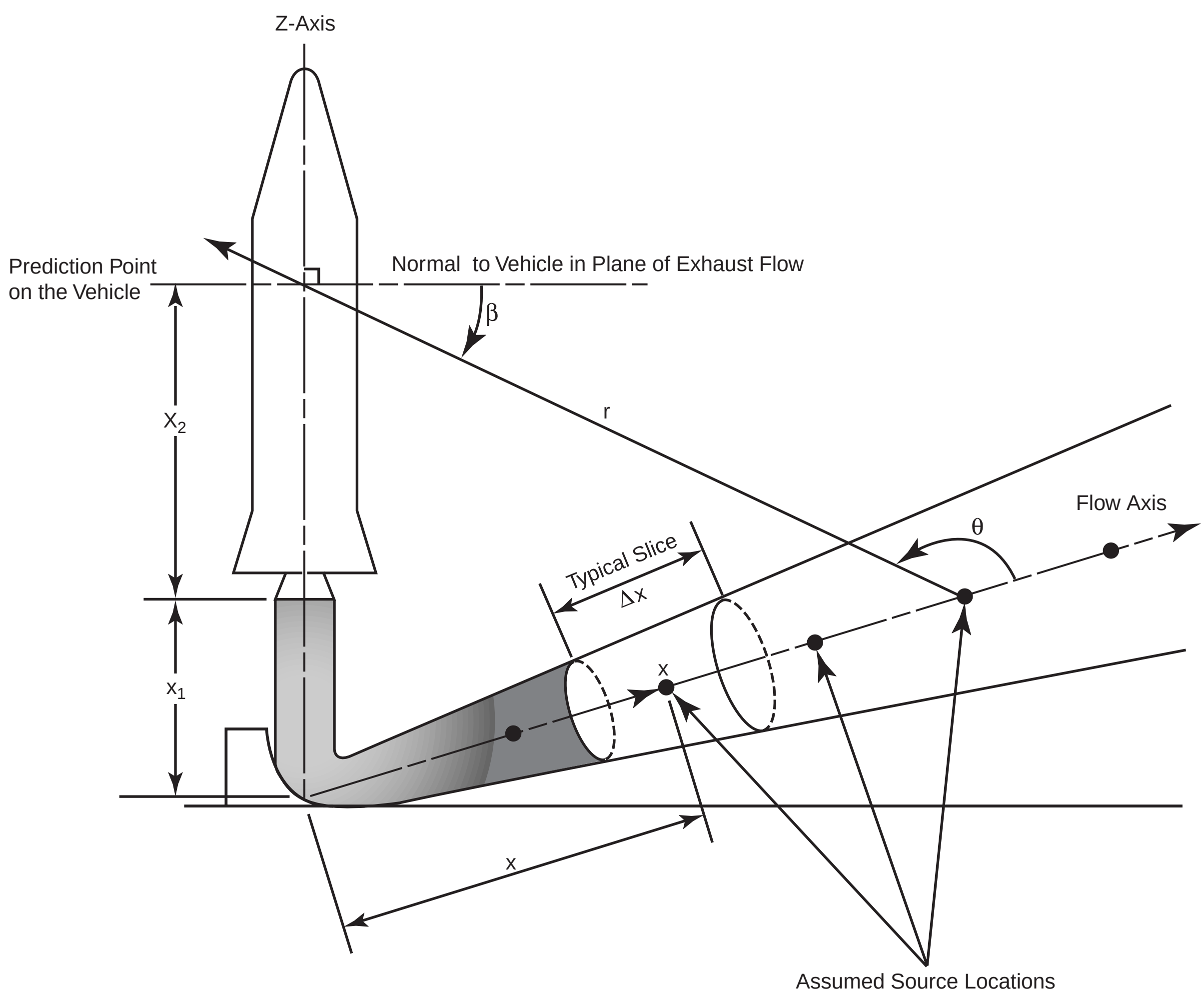
Rocket Noise Prediction Technology

During a rocket launch, structures in the proximity of the launch pad are subjected to an intense acoustic environment generated by rocket exhausts. Launch acoustic levels (greater than 160 decibels) represent a significant load on the spacecraft, ground facilities, and equipment. The design of some structures, particularly those having a large area-to-mass ratio, is governed by launch-induced acoustics that lead to harmful vibration behavior, which manifests itself to the spacecraft and payload in the form of transmitted acoustic excitation and as structure-borne random vibration.

The ground facilities are exposed to severe fluctuating external-pressure loading by the rocket propulsion system during holddown and up to a few seconds after liftoff. The acoustic environment (airborne noise) is severe in the near-field (within 500 to 1,000 feet of the launch pad). Accurate knowledge of near-field acoustic and ignition overpressure loading is necessary to develop acoustic and vibration test criteria for qualification and acceptance testing of many types of ground support and launch equipment.



Source Locations and Geometry

KSC has been involved in the measurement of launch acoustic loads and the development and verification of random vibration response models over the last 30 years. A significant launch acoustic and vibration database exists primarily for ground support equipment. Additionally, the focus has been on developing deterministic models to predict the vibroacoustic response of structures, especially accurate in the low-frequency range (1 to 20 hertz) of launch transients. Lastly, these theories have been validated via physical measurement of launch acoustic loads and simultaneous structural response (vibration and strain) on structures mounted in close proximity (within 300 feet) of the Space Shuttle launch pad.

The purpose of the present project was to develop a comprehensive, automated, and user-friendly software program to predict the noise and ignition overpressure environment and to complement the vibroacoustic prediction effort for existing rockets. More importantly, the program serves a crucial role in the prediction of acoustic loads on such rockets as the X-33 (using new aerospike engines), sea-launched rockets (where the plume impinges in water), and the new-generation launch vehicles with a variety of configurations.

Predictions can be made for single-engine (light) and multiple-engine (heavy) configurations. Acoustic environment predictions are also made for three unique external locations on the vehicle – close proximity of the vehicle mount and two locations in the proximity of the payload. The predictions cover two unique launch scenarios. The first scenario occurs when the vehicle is on the launch mount, which is typical of flight readiness firing (FRF) conditions. The second scenario addresses the supersonic core tip at the launch mount interface, signifying the vehicle nozzle exit plane (NEP) is several hundred feet off the launch pad surface. Predictions are made for varying launch scenarios, mount positions, vehicle configurations, and vehicle locations for a variety of rocket engine configurations and for both open-duct and closed-duct scenarios.

The software represents enormous cost savings since a multitude of sensitivity checks pertaining to the design of launch and spacecraft infrastructure may be determined in the early budgetary and design phases. The software with modifications may be used to predict environments for future rockets that will be deployed in the Martian atmosphere.

Key accomplishment:

- 1999: Developed and enhanced rocket noise prediction software.

Key milestone:

- 2000: Efforts will be aimed to add limited vibroacoustic capability.

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Near-Field Calibration System for Microwave Landing System Certification

The Space Shuttle Microwave Scanning Beam Landing System (MSBLS) ground stations located at the Space Shuttle primary and contingency runways must be calibrated or checked periodically to verify the system is working properly. The MSBLS transmits azimuth and elevation angle information to the Space Shuttle and responds to range interrogation signals from the Space Shuttle. Presently, each runway is calibrated every 2 years by a Flight Inspection System (FIS) or by a Boresight Measurement System.

The MSBLS FIS is a pallet-mounted set of instrumentation consisting of computers, MSBLS and Global Positioning System (GPS) receivers, and data acquisition interfaces. This system is flown into the MSBLS volume of coverage, which compares the position of the aircraft that is derived from carrier phase differential GPS signals to the position of the aircraft that is derived from the received MSBLS signal. The results of the comparison are presented by means of displaying the errors graph on the CRT display to engineers on the aircraft who determine if a correction to the MSBLS is necessary. If needed, corrections to the ground stations are made in real time and the test is repeated to verify the adjustment corrected the errors.

The Boresight Measurement System uses an electronic transient (ET) to determine the position of a MSBLS antenna mounted on a 50-foot mobile tower. The elevation and azimuth angles are calculated from the ET measurements and compared to the corresponding angles determined from the MSBLS signal. Engineers then determine if a correction is required and repeat the bore sight if one is made. The response to the range interrogation is verified by using a Space Shuttle MSBLS receiver decoder and radio frequency unit Flight Equivalent Units (FEU's), which interface to a laptop computer that reads the range. The bore sight method does not check the entire volume of coverage as the FIS does but is expectable when MSBLS ground station repairs require an alignment check or an aircraft is not available to recertify the runways for Space Shuttle use of the MSBLS.

The Near-Field Calibration System (NFCS) development is a combination of the FIS and the Boresight Measurement System. The NFCS has the Space Shuttle MSBLS FEU's to receive the MSBLS signal and decode the azimuth and elevation angles and interrogate the MSBLS ground station for range calculation. The NFCS also has the carrier phase differential GPS equipment to use for the reference data to determine the error in the MSBLS data. As in the FIS, the error information is displayed in real time to the operator. Signals from the NFCS MSBLS ground station and the GPS for the NFCS are received from a MSBLS/GPS antenna assembly mounted on a 50-foot mobile tower. Carrier phase differential GPS corrections are received over a UHF data link as in the FIS.

The NFCS was tested this year during flight inspections at the KSC and Trans-Atlantic Abort Landing Sites and gave the same results as the FIS. The Boresight Measurement System was also used during these inspections, and the NFCS GPS data was compared to the ET measurements, which showed the two reference systems to agree within 0.020° of azimuth and 0.030° of elevation. The NFCS will have more testing and improvements this year.

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Section II

Partnerships and Cross-Cutting Technologies

- Life Sciences and Environmental Engineering and Management
- Workforce Development and Management Systems
- Information Systems
- Safety and Mission Assurance

Life Sciences and Environmental Engineering and Management

Landscape Management and Risk Analysis

Land management practices in many ecosystems, including KSC, are based on controlled burning for habitat maintenance and reduction of wildland fuels. Available ecosystem models and fire and smoke models provide some guidance; however, no system currently exists that incorporates these tools with operational schedules such as payloads, vehicle processing, current meteorological data, and remotely sensed data for use in decision support and risk assessment.

The approach to this project involves development of a diverse set of information tools including rule-based expert systems, numerical models, time series analysis, and fusion of a variety of data collection systems and databases such as fire prescriptions and fuels data, ecological and fire models, real-time meteorological data, and high-resolution aerial imagery. The project will:

- Provide data and information to optimize the management of resources at KSC and the Merritt Island National Wildlife Refuge.
- Incorporate NASA remote sensing and advanced Geographic Information System (GIS) technology into local-scale decisionmaking processes.
- Provide information and methods to reduce the potential for wildfires at KSC.
- Enhance NASA's capabilities to comply with Federal and State environmental laws such as the Endangered Species Act.

Key accomplishments:

- 1996: Obtained a high spectral resolution image of the KSC area using the NASA AVIRIS sensor. Initiated development of a deterministic model for estimating plant canopy biochemical and biophysical characteristics.
- 1997: Conducted an experimental controlled burn at KSC in association with the U.S. Fish and Wildlife Service, Los Alamos National Laboratory, U.S. Air Force, and Los Angeles County Fire Department to develop data on fire spread, intensity, and smoke production. Obtained high spatial resolution images (1 to 2 meters) of KSC. Obtained field measurements of plant canopy biophysical and biochemical features and plant

Successful Smoke Management During a Controlled Burn Approximately 1 Mile North of the Vehicle Assembly Building

Department of Interior Secretary Bruce Babbitt Igniting a Controlled Burn at KSC During the Multiagency Research Activity Into Fire and Smoke Modeling

canopy and leaf spectral characteristics for model development and parameterization.

- 1998: Initiated development of a World Wide Web-based decision support tool that integrates payload schedules, Shuttle operations schedules, facility locations, and controlled burn prescriptions to minimize conflicts and maximize management of wildland fuels and wildlife habitat. Integrated plant biophysical features such as leaf area, leaf angle distribution, canopy closure, canopy height, and bottom reflectance into a two-flow irradiance model for radiative transfer in plant canopies.
- 1999: Enhanced fire management information development and transfer with the Fire Management and Analysis Network (FireMAN). Acquired high-resolution Light Interferometric Detection and Ranging (LIDAR) data for development of a three-dimensional landscape model.

Key milestones:

- 1996: Initiated GIS database integration in Oracle and development of image processing methods for use of high spectral resolution data in wildlife habitat mapping. Presented two papers at the Eco-Informa Conference in Orlando, Florida, on remote sensing modeling in plant canopies.
- 1997: Coordinated a multi-agency experimental controlled burn to obtain data on fire and smoke behavior in coastal environments.
- 1998: Enhanced communications between the U.S Fish and Wildlife Service and NASA Shuttle and Payloads Operations through development of a Web-based support system for controlled burns at KSC.
- 1999: Initiated a multi-agency effort to support fire management and response activities with NASA, the U.S. Air Force, County Emergency Management, and Florida Division of Forestry.

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Participating Organization: Dynamac Corporation (R. Schaub and C. Hall)

Possible Use of Solar Radiation Shields on Mars

Cryogenic refrigerators of the size planned for Mars are about 10 percent efficient. Reducing the heat transferred to the cryogenic refrigerators, storage containers, and systems from the sun would greatly reduce the power required on Mars. The atmospheric pressure on Mars is approximately 7 torr (0.1354 pound per square inch). This low pressure results in a low atmospheric density and low heat transfer to the cryogenic hardware by conduction. Consequently, most of the environmental heat transfer to the cryogenic systems will be from radiation heat transfer from the sun. It is believed that heat transfer from the sun can be reduced with radiation heat transfer barriers called shadow shields. Initial tests have shown the concept to be effective.

A test was set up in an environmental chamber using a 20-watt light bulb, an aluminum plate, and a shadow shield as shown in figure 1. The shadow shield reduced the heat transfer in different environments as shown in figure 2. This carbon dioxide (CO_2) test used a CO_2 flow rate of 20 milliliters per minute. It is believed this flow of CO_2 caused convective heat transfer. Further testing with more shadow shields is needed to determine the equations to design shadow shields on Mars. The shield was made from a piece of silverlux specular silver reflective film made by the 3M Company.

Key accomplishments:

- 1999: Estimated the solar heat input on Mars with transient daily temperatures. Constructed a shadow shield test model. Ran tests on a single shield. Evaluated the results. Prepared the test report. Planned further testing with multiple shields. Developed a concept of a shield on Mars moving in relationship to the sun.

Key milestones:

- 2000: Construct a shadow shield test for five shields. Run tests. Determine the heat transfer reduction as a function of the number of shields. Prepare a test report.
- 2001: If tests in 2000 are successful, build, test, evaluate, and report on a small solar tracking device.

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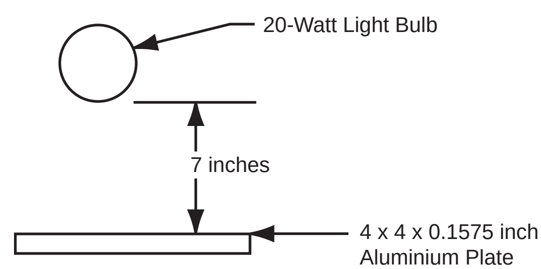


Figure 1. Shadow Shield Test Arrangement

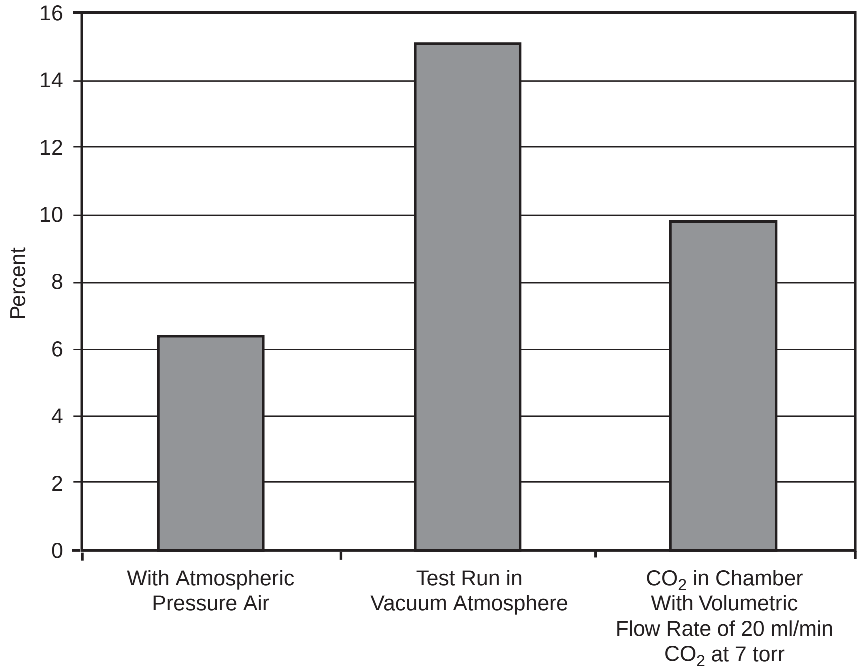


Figure 2. Percent of Heat Shielded

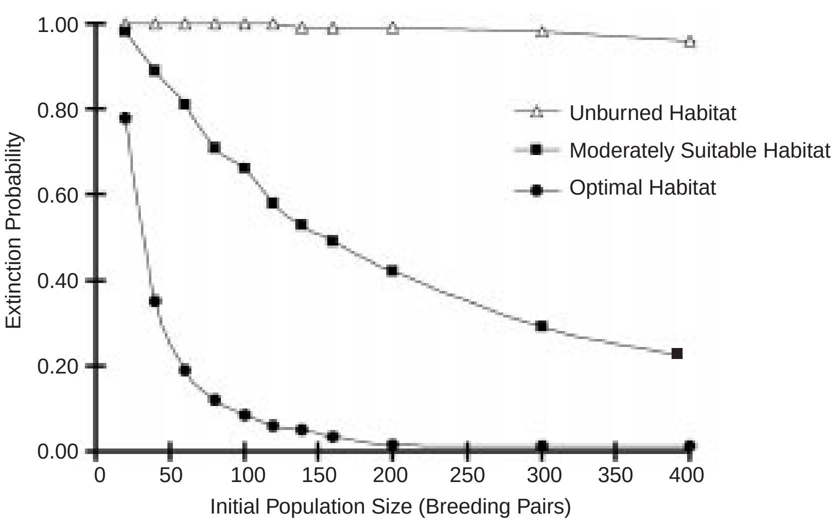
Threatened and Endangered Species Monitoring

The habitats on KSC represent an area of biological diversity unsurpassed among Federal facilities. Under the Endangered Species Act and the National Environmental Policy Act, operations require evaluation and impact minimization. Approximately 100 wildlife species on the Merritt Island National Wildlife Refuge are species of conservation concern. Monitoring focuses on combining field and remote sensing data with predictive/interpretive models on marine turtles, gopher tortoises, indigo snakes, wading birds, shorebirds, scrub jays, beach mice, and manatees. These studies contributed to more than 25 scientific journal articles and were used to develop rangewide species recovery efforts.

The influence of habitat on demographic success is quantified at different spatial scales. Monte Carlo simulation models are used to quantify the influence of habitat quality, population size, and catastrophes on populations. Sequences of aerial photography show that habitat suitability is declining because of reduced fire frequencies. Habitat fragmentation and declining habitat quality were found to be a critical factor influencing extinction risk, indicating more frequently prescribed fires are needed.

Key accomplishments:

- 1991: Developed habitat maps of the most important areas at KSC for scrub jays, wading birds, and other species.
- 1992: Developed a scrub restoration and monitoring program.
- 1993: Developed a wetlands restoration program plan.
- 1994: Developed a KSC biological diversity evaluation summary.
- 1995: Developed techniques to map habitat suitability.
- 1996: Developed models to predict demographic success using maps.
- 1997: Tested the ability of maps and models to predict populations.
- 1998: Developed rapid assessment tools for environmental managers.
- 1999: Developed procedures to include uncertainty into decisionmaking.



Influence of Habitat Extent and Suitability on Florida Scrub Jay Populations (Each pair requires an average of 25 acres.)

Key milestones:

- 1995: Population and habitat status trends summarized for gopher tortoise, wading birds, and scrub jays.
- 1996: Development of scrub jay population recovery strategy.
- 1997: Biological diversity prioritization analysis published.
- 1998: Habitat analysis procedures published.
- 1999: Population risk modeling procedures published.

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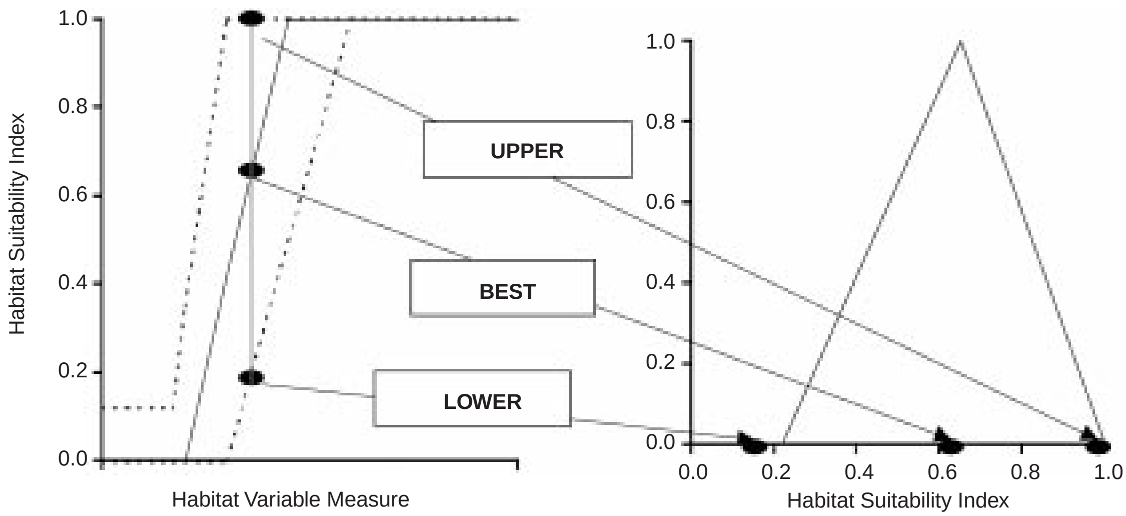
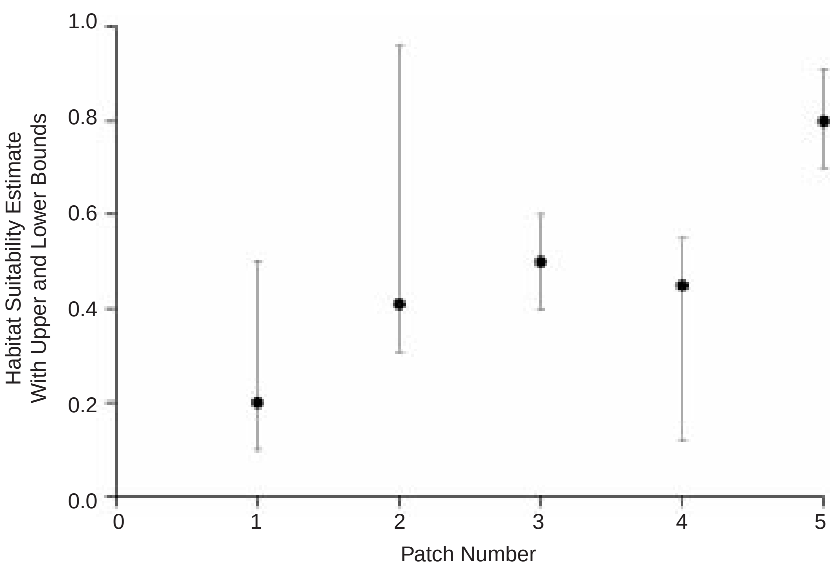
Participating Organization: Dynamac Corporation (D.R. Breininger)



How Uncertainty Is Propagated Using Triangular Distributions and Fuzzy Numbers
(These types of analyses can accommodate the many types of uncertainties associated with habitat suitability indices and propagate boundaries faithfully through a chain of calculations. Greater application of such techniques could substantially improve the quality of natural resource decisionmaking.)



(The attitude to risk and the context of the decision problem change the way sites should be ranked. Patch 5 should always be regarded as superior habitat. However, the choices among other patches depend on factors such as whether the cost of being wrong is catastrophic. When the distributions of reliability are skewed, opportunities can exist for improved decisionmaking. It may be considered worthwhile to protect patch 2 rather than patch 3 because the upper boundary of the estimate is much higher.)

Fuzzy Numbers Representing Habitat Suitability for Five Habitat Patches

Pilot-Scale Evaluation of Hydrogen Peroxide Injection Coupled With UV Photolysis To Control NO_x Emissions From Combustion Sources (Phase II)

Nitrogen oxides (NO_x) are a primary air pollutant regulated by the Environmental Protection Agency with the majority of emissions in the form of nitrogen oxide (NO). There is an increasing interest by industry in control technologies to remove NO_x from flue gas streams as regulatory restrictions on emissions are tightened. As part of an ongoing effort to research and demonstrate the removal of NO_x from stationary combustion sources, the Government/academia/industry team of NASA, the University of Central Florida, and EKA Chemicals, Inc., has been conducting studies at KSC over the past 3 years. Their efforts targeted power plant applications during the first 2 years of the study and lower temperature flue gas streams during the past year. The studies are intended to demonstrate new NO_x control technologies at the pilot scale. The tests were conducted on a portion of the flue gas stream from a 35 million British thermal units per hour boiler located on site at KSC.

The new technology involves the injection of hydrogen peroxide (H_2O_2) into hot flue gases to oxidize the NO into nitrogen dioxide (NO_2) and the acid forms (HNO_2 and HNO_3), which can then be removed in a wet scrubber. A substantial pilot plant was designed, constructed, and operated at KSC. The pilot plant data confirmed earlier laboratory results that H_2O_2 is very effective at oxidizing NO; conversions of NO above 90 percent were obtained at temperatures of about 500 °C (930 °F) and molar ratios of H_2O_2:NO_x slightly above 1.0. In the pilot plant, it was observed that the NO_2 was not oxidized to HNO_2 and HNO_3 to the same extent that occurred in the laboratory studies. The speciation conversions were studied at the end of the Phase II testing, after system modifications, to determine whether it was possible to move the reactions further to the acid species. The results were not conclusive.

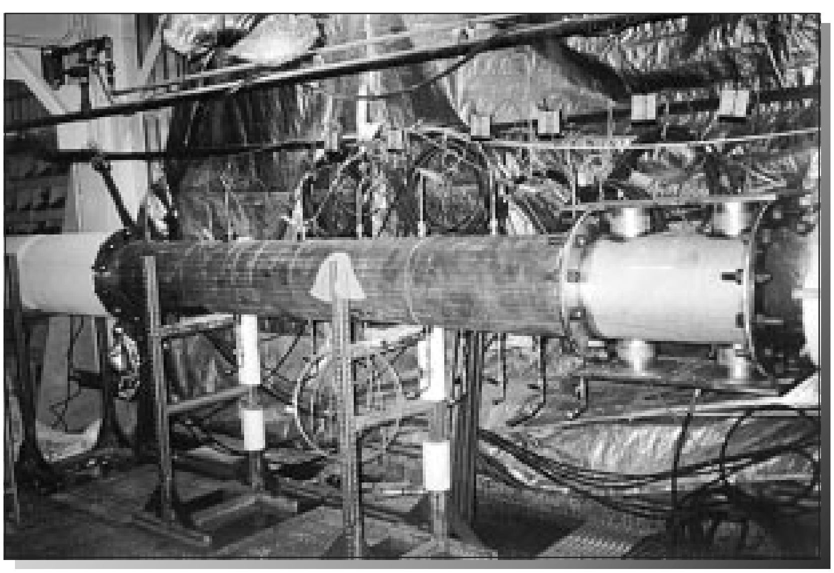


Figure 1. Uninsulated Reactor With a UV Spool Inserted Upstream

The primary research objective, conducted in 1999 under Phase II, was to try to activate the H_2O_2 at temperatures in the range of 200 °C, to improve NO_2 conversion, and to optimize the removal of NO_2 in the scrubber. Ultraviolet (UV) photolysis was utilized to activate the H_2O_2 in lieu of high temperatures. Figures 1 and 2 show the UV system installation located at the upstream end of the reactor. Also during Phase II, the scrubber was modified (see figure 3) to increase the efficiency and semi-automate the pH and temperature controls. The modifications to the scrubber allowed the researchers to characterize the scrubber operational parameters for the species in this study and were intended to improve the

Figure 2. UV System

Figure 3. Scrubber Tower and Reservoir

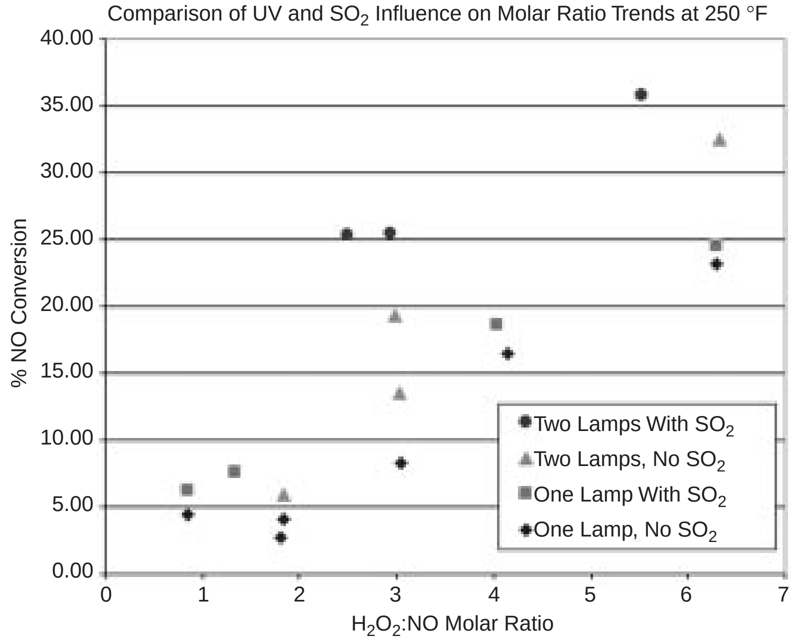


Figure 4. Results From Phase II Tests Utilizing H_2O_2 Activated by UV Radiation

removal of the NO_2. The tests were conducted both with and without sulfur dioxide (SO_2) to characterize the sensitivity of this technology on sources where SO_2 is present. As seen in figure 4, the tests were also conducted at two different flux levels of UV radiation (with one lamp and with two lamps), and the NO removal efficiency improved both in the presence of SO_2 and at the higher flux for similar H_2O_2:NO molar ratios.

Key accomplishments:

- 1997: Completed Phase I design, installation, and preliminary testing.
- 1998: Completed Phase I testing, data analysis, and reports. Presentations at the Air and Waste Management Association's (AWMA) section meetings.
- 1999: Completed Phase II design, testing, data analysis, and reports. Presentations given at the AWMA Annual Conference and AWMA Florida section meeting. Modified system and reran short grouping of Phase I level tests for repeatability verification and speciation enhancements.

Key milestone:

- 2000: Phase III design, testing, data analysis, reports, and presentations at technical forums.

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Participating Organizations: University of Central Florida (Dr. C. D. Cooper; Dr. C.A. Clausen, III; and Dr. J.D. Dietz) and EKA Chemicals, Inc. (J. Tenney and D. Bonislawski)

Candidate Crop Evaluation for Advanced Life Support and Gravitational Biology and Ecology

The primary objective of this task is to define the environmental conditions and horticultural methodologies to optimize both edible biomass production and life support functions in candidate crop species. Environmental conditions include carbon dioxide concentration, light quality and quantity, temperature, relative humidity, and nutrient media elemental concentrations. An important consideration of this task involves the screening of different cultivars of candidate crops and the compilation of all crop growth data for inclusion in a crop handbook. This effort will use a standardized testing procedure for all candidate crop species selected from the Crop Selection Meeting held at KSC in May 1997. Development of crop management strategies for reuse of nutrient solutions with a special emphasis on biologically active organic materials that may accumulate in the nutrient solution is being addressed. This task includes the coordination of NASA-supported tasks at the New Jersey NASA-Specialized Center of Research and Training (NJNSCORT) for tomato and salad crops; at the Tuskegee Institute for peanut and sweet potato; at Utah State University for wheat, rice, and soybean; and NASA Research Announcement (NRA) grant recipients for other candidate crops. Other significant collaborations include Cornell University for dry and snap bean and spinach research.

The development of a bioregenerative life support system requires that the horticultural methodologies and the range of suitable environmental conditions for various candidate crops be well understood. This is an integrated activity requiring coordination with several research organizations and ongoing Advanced Life Support (ALS) tasks in order to maximize the benefit to the ALS program.

The candidate crop research conducted at KSC during 1999 included:

- Beans: Tests were initiated to determine the growth and yield characteristics of both dry beans (cv. Etna) and snap beans (cv. Hystyle) at varying levels of carbon dioxide in collaboration with Cornell University.

- Table beet: Tests were conducted to determine the ability of table beet to accumulate sodium in the plant tissues in collaboration with the National Research Council (NRC).

- Spinach: Tests were conducted to determine the effects of narrow-band spectral radiation provided by light-emitting diodes (LED's) on the growth and yield of spinach in collaboration with the ALS lighting task, KSC Director's Discretionary Fund, Cornell University, and the LED NRA.

- White potato: Tests were conducted to determine the management approaches for reuse of hydroponic nutrient solutions for successive generations of potato crops.

- Wheat: Tests were conducted in collaboration with the resource recovery-water recovery task to determine the dose-response effect of gray water (Igepon) on the growth and yield of wheat to determine the effect of additions of leachates produced from composted inedible wheat biomass on the growth and yield of wheat.

Key accomplishments:

- 1998: Completed experiments investigating the effects of short-term photoperiod changes on the photosynthetic capacity and carbohydrate accumulation in beans. Completed experiments investigating the effects of different methods of gray water (Igepon) additions on the growth and yield of wheat and lettuce.
- 1999: Completed experiments investigating the effects of additions of leachates of composted inedible wheat biomass to the nutrient solution on the growth and yield of wheat. Completed experiments investigating the dose-response of gray water (Igepon) on the growth and yield of wheat. Ten peer-reviewed articles were either published or accepted for publication.

Key milestones:

- 2000: First edition of the crop handbook for ALS candidate crops. Completion of filtered versus unfiltered compost leachate tests on wheat. Completion of LED tests with salad crops.
- 2001: Completion of tests investigating the effects of carbon dioxide on beans.

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Participating Organizations: Dynamac Corporation (Dr. G.W. Stutte and N.C. Yorio), Utah State University (Dr. B. Bugbee), Cornell University (D. DeVilliers, C.F. Johnson, and Dr. R.L. Langhans), NRC (Dr. G. Subbarao), Rutgers University (Dr. H. Janes), and Tuskegee University (Dr. D. Mortley)

Snap Bean (cv. Hystyle) Grown Under Elevated CO_2 Conditions at the Life Science Support Facility

Dry Bean (cv. Etna) Grown Under Elevated CO_2 Conditions at the Life Science Support Facility

Graywater Processing in Bioregenerative Life Support Systems for Space Exploration

Just as in terrestrial homes, graywater (nontoilet wastewater) is projected to be the largest waste stream (by mass) generated in long-term crewed space habitats. Estimated graywater production rates (27 liters per person per day) could comprise 80 percent of the total waste output. Incorporation of graywater into hydroponic plant production systems and subsequent recovery of the water transpired by the plants are a potential means for water purification and recycling in bioregenerative life support systems. In this approach, microorganisms associated with plant roots are responsible for degrading the surfactants and other organic material contained in the graywater. An alternative biological processing approach involves treatment of the graywater by microorganisms in bioreactors, such as fixed film bioreactors (FFB), prior to incorporation into plant growth systems.

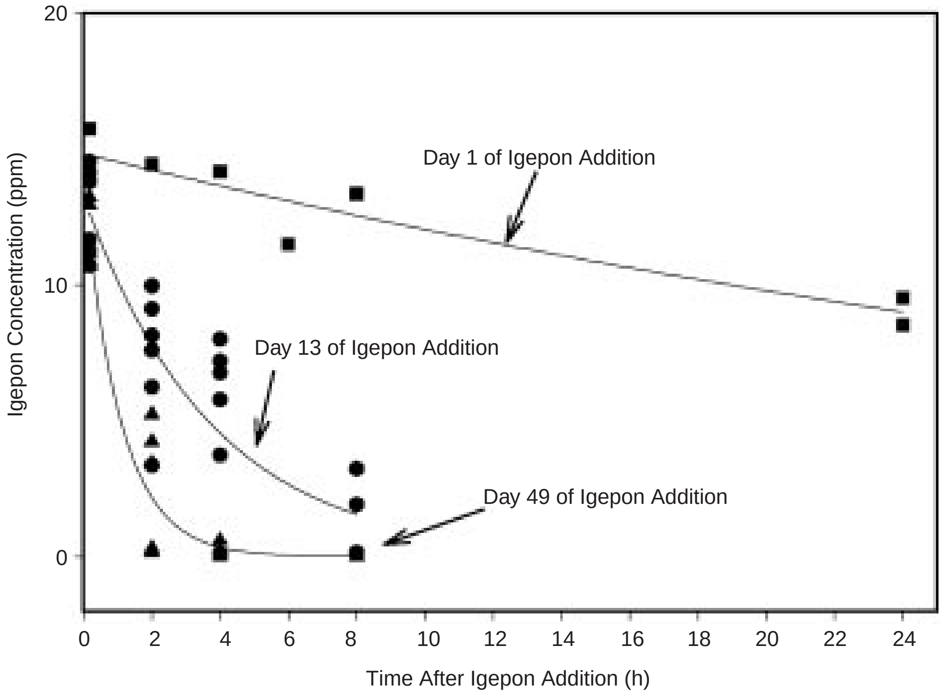
The viability of the direct recycling approach depends on better understanding of the relative degradation rates and phytotoxicity of the surfactants in the graywater as well as the potential survival of human-associated microorganisms. The microbiological issues are addressed in a separate technology report (Microbial Ecology of Bioregenerative Life Support Systems for Space Exploration). The initial studies of surfactant degradation and phytotoxicity focused on Igepon, the cleaning product designated for use on the International Space Station. Research during the past 2 years evaluated the effects of adding both actual and simulated Igepon-containing graywater streams into plant production studies with soybean, wheat, and lettuce. Igepon was rapidly degraded in the systems, and no negative effects on plant growth were observed except when very high loading rates of Igepon were added to lettuce studies.

Data contained in the graph reflects the increased rate of Igepon degradation over time, ranging from almost no degradation within 24 hours on the first day of addition to complete degradation within 2 hours on day 49 of addition. These data indicate the hydroponic systems are very effective bioreactors for degrading Igepon following an initial enrichment period.

Current work is examining the phytotoxicity and biodegradation of surfactants commonly found in commercial personal care products (e.g., bar soaps and shampoos). This work will determine the potential effects of using common cleaning products in space, as well as test the applicability of these graywater processing approaches for terrestrial applications. Seedling phytotoxicity studies were initiated, while small- and intermediate-scale bioreactor and plant studies are planned for next year.

Key accomplishments (1999):

- Completed studies on recycling of simulated graywater (i.e., Igepon) in hydroponic systems containing lettuce and wheat.
- Published previous studies on recycling actual graywater streams (i.e., shower and laundry water) in hydroponic systems containing wheat and soybean.
- Initiated seedling assays to test phytotoxicity of alternative surfactants.
- Developed enrichment cultures of microbial consortium able to degrade the alternative surfactants.



Igepon Concentration in Nutrient Solution of Hydroponic Systems

- Developed analytical methods for monitoring the concentration of different surfactants in bio-processing units.

Key milestones (2000):

- Publish findings of simulated graywater recycling studies with wheat and lettuce.
- Publish the evaluation of the phytotoxicity of alternative surfactants.
- Complete the initial evaluation of the comparative biodegradation of alternative surfactants.
- Initiate recycling studies with mixtures of actual graywater streams containing multiple surfactants.

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Participating Organization: Dynamac Corporation (J.L. Garland and Dr. L.H. Levine)

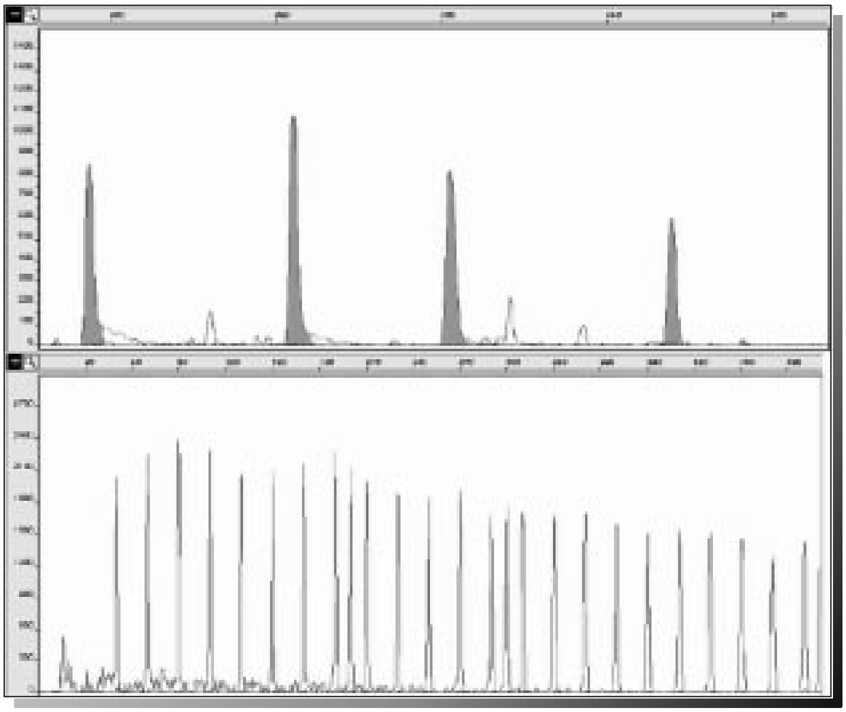
Microbial Ecology of Bioregenerative Life Support Systems for Space Exploration

The stability of microbial communities within closed bioregenerative systems is an important component of overall system stability due to the risk of human or plant disease and the reliance on microbial-based reactors for waste processing. Effective management of microbial communities requires an improved understanding of the complex interactions among microorganisms within Advanced Life Support (ALS) systems, which in turn depend on advancements in rapid and reliable monitoring techniques. The purpose of this work is to develop monitoring tools that allow for a better understanding of the microbial risks associated with bioregenerative life support systems and to evaluate the suitability of these tools for use in lunar or Mars bases. Experiments with prototype ALS subsystems under development at KSC (e.g., plant production systems and bioreactors) will assess the ability of different techniques to identify changes in the overall stability of microbial communities and detect the presence of specific human or plant pathogens before the health of the system is adversely affected. These efforts will help identify the best approaches for managing microbial risks within the systems in addition to evaluating specific sensor technology.

The primary effort this year involved the development of molecular tools for assessing microbial communities in bioregenerative ALS systems. The infrastructure at KSC to perform molecular analysis was expanded through the addition of an ABI Prism 310 Genetic Analyzer from Perkin Elmer. This instrument allows for automated DNA fingerprinting (i.e., nucleotide sequencing and molecular genotyping) through capillary electrophoresis and fluorescent detection. DNA fingerprinting can identify microbial isolates and characterize complex microbial communities that contain culturable and nonculturable organisms. Most efforts in the past year focused on characterizing microbial communities from a long-term plant growth study with potato and a series of composter trials using one community profiling technique, Terminal Restriction Fragment Length Polymorphisms (T-RFLP's).

Development continued on a rapid, simple monitoring method for analyzing microbial communities based on functional profiling. This approach, term community-level physiological profiling (CLPP), is based on respiration of 95 separate carbon sources within microtiter plates and automated detection of concomitant color production due to the reduction of a redox sensitive dye. The advanced analytical software for analyzing the kinetic profile of color development written during the last fiscal year was used to characterize microbial communities from ongoing ALS studies. A novel extension of this approach was developed to rapidly assess microbial diversity.

The project also continued to quantify the survival of human-associated microorganisms within plant growth systems to assess microbial risks. The persistence of the polio virus in hydroponic systems was tested in collaboration with researchers at the American Water Works Service Company. Survival of three potentially pathogenic human-associated bacteria (*Staphylococcus aureus, Pseudomonas aeruginosa, and Escherichia coli*) was assessed as part of graywater processing studies with wheat. A University of South Florida student completed a dissertation dealing with the factors affecting survival of *Pseudomonas aeruginosa* in hydroponic systems and began work at the U.S. Department of



T-RFLP Patterns Produced Using the ABI 310 Genetic Analyzer [Lines represent lane markers (internal controls) and shaded areas reflect terminal restriction fragments of rhizosphere populations.]

Agriculture (USDA) Agricultural Research Service. Collaborative efforts will be continued with the USDA as the work with biocontrol of human pathogens on fresh vegetable products such as lettuce and spinach is initiated.

Development of a miniature biosensor for surfactant detection also continued in collaboration with the Center for Environmental Biotechnology at the University of Tennessee. This work involves fusion of the *lux* gene into the promoter elements for the gene coding for the surfactant degrading enzyme and subsequent use of light production as a rapid, on-line measure of surfactant concentration.

Key accomplishments (1999):

- Received a certificate of recognition for creative development of a technical innovation (i.e., CLPP technique).
- Obtained and installed an ABI 310 Genetic Analyzer from Perkin Elmer into KSC laboratories.
- Completed studies evaluating survival of human-associated viruses and bacteria in hydroponic systems.
- Completed a publication outlining the use of the CLPP approach for rapidly assessing microbial diversity.
- Initiated a collaborative effort with the University of Tennessee to develop a bioluminescent bioreportor for surfactant detection.

Key milestones (2000):

- Publish an evaluation of new CLPP software and distribute the product to interested research organizations.
- Publish findings from the initial application of T-RFLP molecular analysis to KSC studies.
- Receive the miniaturized biosensor for surfactant detection from the University of Tennessee and begin testing at KSC.
- Install the instrument for quantitative polymerase chain reaction detection and apply it in studies evaluating pathogen survival in bioreactors.
- Initiate collaborative efforts with USDA dealing with the biocontrol of human pathogens on food.

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Technical Development and Integration of Advanced Life Support (ALS) Systems

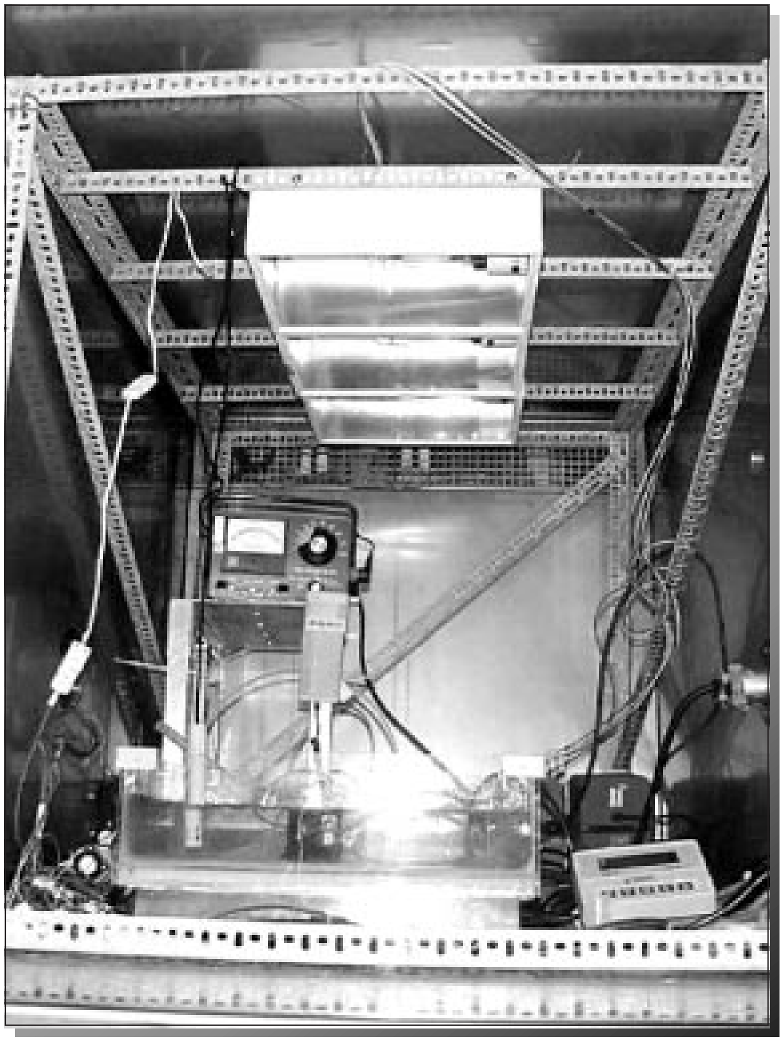
The objective of this task is to develop and increase the Technology Readiness Level (TRL) of bioregenerative ALS components, such as bioreactors, plant growth chamber subsystems, sensors and control systems, and database management systems. This work involves coordinating efforts with outside entities such as universities and private businesses and will involve the testing of specific equipment resulting from grants and SBIR's. The automation of biomass production systems and resource recovery systems, including both monitor and control, and physical automation are evaluated. The development of an ALS Automated Remote Manipulator (ALSARM) with appropriate end-effectors will demonstrate physical automation of plant growth environment monitoring and harvesting. The focus on monitor and control automation will utilize system data in model-based control for predictive, expert-system decisionmaking. An improved monitoring and control system based on commercial off-the-shelf (COTS) software will improve data utility and minimize maintenance time and logistics support requirements. The development of an ALS database system and the integration of past and real-time data will provide answers and directions to future projects. This task will promote technical development and the integration of system components required to reduce the equivalent system mass (ESM) and enable biomass production while increasing operational reliability. Systems designed to automate operation, use expert control capabilities, and incorporate higher level database storage and feedback will result in significant ALS development cost and time savings and will lead to better safety and reliability.

Key accomplishments:

- Mars Deployable Greenhouse Project: Characterized the leak rate of the thermotron vacuum chamber that will be used to simulate the Martian environment. Collected the preliminary data on lettuce transpiration rates, humidity sensing and control, and dissolved oxygen at reduced pressures. Designed the hardware to accommodate the humidity control in the chamber.
- Bioreactors: Designed the pilot-scale fixed-film bioreactor (FFB) for a solid waste treatment comparison study. Integration and testing of membrane separation technology with Mainstream Engineering.
- ALSARM: Designed a wrist manipulator end-effector for a robot through the University of Central Florida design class.
- Data Acquisition and Control: Integration of the hardware (OPTO22) and software (G2) platform using OPTOMUX protocol. Development and refinement of software capabilities to control plant growth chambers 16 and 17. Development of the driver for existing OPTO22 digital/analog hardware with a graphical interface.
- Databasing: Incorporated a new data model for all ALS data to improve query efficiency and functionality. Developed a new front-end graphical interface in Microsoft Access for viewing and querying data.

Key milestones:

- Develop and integrate an environmental monitoring and control system for the Mars simulation vacuum chamber.



Vacuum Chamber for Plant Growth Experiments in Reduced Pressure

- Conduct plant growth studies in reduced pressures at constant temperature, carbon dioxide, light level, and humidity.
- Development and testing of hardware for the ALSARM wrist manipulator end-effector.
- Integrate chambers 2 to 5 and ALSARM into the ALSACT control system.
- Develop modular control objects within a G2 knowledge base to integrate with the driver.
- Collaboration with Jim Wright Environmental to develop and test a more rapid, efficient solid-waste processing unit.
- Collaboration with the University of Florida to port the database to the Internet.
- Design a higher level object-oriented database that integrates with the control and decisionmaking process.

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Participating Organizations: Dynamac Corporation (S. Young), Matrix Information Systems (B. Payne), University of Central Florida (Dr. R. Johnson), University of Florida (Dr. R. Bucklin), and Mainstream Engineering (D. Back)

Advanced Life Support (ALS) Resource Recovery and Biomass Processing Research

Resource recovery and biomass processing are major components of a functional Controlled Ecological Life Support System (CELSS), along with biomass production, crew, and system integration. The challenge has been to recycle inedible material into carbon dioxide and mineral forms that can be used by crops and to convert these inedibles into food, thus more efficiently using ALS energy, volume, weight, and crew time.

The ultimate goal has been to design, fabricate, test, and operate (at a breadboard scale) ALS biomass processing and resource recovery components. Candidate processes are identified and studied with small, laboratory-scale (0.1- to 2-liter size) systems to identify key environmental and process control parameters. Intermediate-scale systems (i.e., 8- to 10-liter size) are then used to optimize these key process parameters and to gain operational experience with the potential hardware, software, process control and monitoring, and biological subsystems. Then, the full-scale components are designed, fabricated/procured, set up and tested, operated, and integrated with the other systems within the ALS breadboard. The following ALS resource recovery research continued to focus this year on aerobic composting of inedible crop residues:

1. Integration studies at the intermediate scale – optimized composting, design of a leaching process for recovery of inorganic nutrients from composted material.

2. Assessment of the potential role and costs/benefits of aerobic composting of inedible crop residues, leading to the eventual incorporation of composting at a larger scale [Johnson Space Center (JSC) BIO-Plex or Advanced Life Support Integrated Test Bed (ALSITB)].

3. Literature review and design of a student research project to examine the development of a mixed microbial inoculum to be used to improve, via this bioaugmentation, the degradation of crop residue polysaccharides, such as cellulose and hemicelluloses.

A NASA Research Announcement (NRA) grant with a duration of 4 years was initiated. This study will compare key bioprocess technologies [continuously stirred tank reactor (CSTR) versus composting versus fixed-film bioreactors] to determine costs/benefits with the limited goal of rapid recycling and recovery of inorganic crop nutrients from ALS solid wastes. Both inedible crop residues and human fecal wastes will be included in the NRA. Thus, this will be KSC's first look at bioprocessing human fecal wastes with the goal of recovering resources.

Next year, resource recovery will continue to focus on aerobic composting of inedible crop residues in a study to determine the effects of thermal regime (isothermal versus conventional mesophilic and thermophilic stages) on survival of potential human pathogens from fecal wastes. Molecular biology techniques will be used to determine survival and persistence of indicator and model microbial contaminants. The NRA will also focus on optimization of the three bioprocess technologies leading to a comparative integrated study of rapid bioprocessing of solid wastes with nutrient recycling to crop hydroponic production systems. The development of small, "mixed" composting systems will be studied in a collaborative arrangement with an expert composting firm, Wright Environmental Systems.

Key accomplishments:

- 1986 to 1988: Initial cellulose conversion research.
- 1989: Cellulose conversion process optimization studies.
- 1990: Flask-scale studies of cellulose conversion.
- 1991: Completed biomass processing studies on cellulose conversion with five breadboard scale runs.
- 1992: Initiated flask-scale studies of microbial aerobic decomposition of crop residues.
- 1993: Design, fabrication, and operation of intermediate-scale aerobic bioreactors. Design and fabrication of Breadboard-Scale Aerobic Bioreactor (B-SAB).
- 1994: Integration and first operation of B-SAB, recycling nutrients to the Biomass Production Chamber (BPC). Process optimization.
- 1995: Integrated B-SAB with other crops (white potato). Integrated studies of anaerobic biological processing of crop residues with downstream processing components. Process improvement.
- 1996: Completed intermediate-scale tests of bioreactor retention times and aerobic biological processing of crop residues. Initiated aerobic composting for recovery of minerals and carbon from crop residues.
- 1997: Integrated graywater processing into intermediate-level biomass production studies. Continued laboratory-scale composting of crop residue solid wastes and initiated composting of simulated human solid waste. Integrated large-scale bioprocessing of crop residues with nutrient recycling during the 90-day phase 3 test of the JSC Lunar-Mars Life Support Test Project (L/MLSTP).
- 1998: Integrated biological processing of graywater into intermediate-scale composting. Integrated intermediate-scale composting of crop residues with crop nutrient recycling. Initiated intermediate-scale studies of human solid waste bioprocessing. Initiated studies of the effects of inoculation of bioreactors (composters) to increase crop fiber degradation.

Key milestones:

- 1999: Continued the integration of composting of solid wastes with nutrient recycling to hydroponic production of crops. Integrated intermediate-scale biological processing of graywater and human solid wastes with crop production. Continued process optimization with focus on crop fiber degradation. Initiated studies to determine survival and persistence of potential human fecal-borne pathogens through bioprocessing components. Completed evaluation of nutrient recovery from human solid waste.
- 2000: Integrate large-scale composting of crop residues into BIO-Plex-level studies at JSC. Integrate large-scale biological processing of urine and human solid wastes into BIO-Plex-level studies at JSC. Finalize decision on biological processing of human solid waste. Begin integrated tests of bioreactors and physical/chemical systems with Ames Research Center. Complete development of prototype material for plant growth initiation using bioreactor solids.
- 2001: Complete biological processing method comparison (solid waste NRA). Complete reactor technology selection for BIO-Plex. Preliminary design of solid waste processing system for BIO-Plex.

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Participating Organization: Dynamac Corporation (R.F. Strayer, Ph.D.)

Plant Nutrient Solution Delivery Systems

The nutrient thin-film technique (NFT) is a hydroponic approach commonly used to manage nutrient delivery to crops being studied for Advanced Life Support (ALS) systems. This approach involves daily replenishment of minerals to maintain a constant nutrient supply for the plants. In general, NFT produces excellent yields with ALS crops when nutrient solution pH and mineral contents were maintained at predetermined setpoints.

Sweetpotato [Ipomoea batatas (L.) Lam.] is one of the crops being studied by NASA's ALS program for future space missions. Unlike aboveground food crops selected for the ALS, storage root production by sweetpotato appears to require special subsurface growing conditions and engineering. Under certain nutrient solution management practices in hydroponic systems, sweetpotato plants exhibit excessive shoot growth and reduced storage root yield. Past research with sweetpotato at KSC and Tuskegee University has shown that mild plant stresses, such as low pH and low nitrogen-to-potassium ratios, can enhance the edible storage root production while limiting vine growth. Studies conducted in conjunction with Tuskegee University compared sweetpotato production in NFT systems either with daily nutrient solution replenishment plus real-time pH control or with nutrient solution replenishment three times per week with only periodic pH control. Results showed that replenishment of nutrient solution on a daily basis produced excessive foliage growth with very little storage root production. Nutrient solution replenishment three times per week produced manageable vine growth and respectable storage root yields. Collectively, these studies showed that a modified management approach for nutrient availability and pH control is critical for sweetpotato storage root production.

Sweetpotato Plants Growing in Growth Chambers Using NFT Hydroponics

Key accomplishments:

- 1997: Initiated a sweetpotato collaborative study with Tuskegee University to compare different hydroponic strategies.
- 1998: Completed comparison studies with different hydroponic strategies to support sweetpotato. Delivered a sweetpotato nutrient protocol to the Johnson Space Center ALS program.
- 1999: Published the research on hydroponic nutrient management strategies for optimizing sweetpotato yields.

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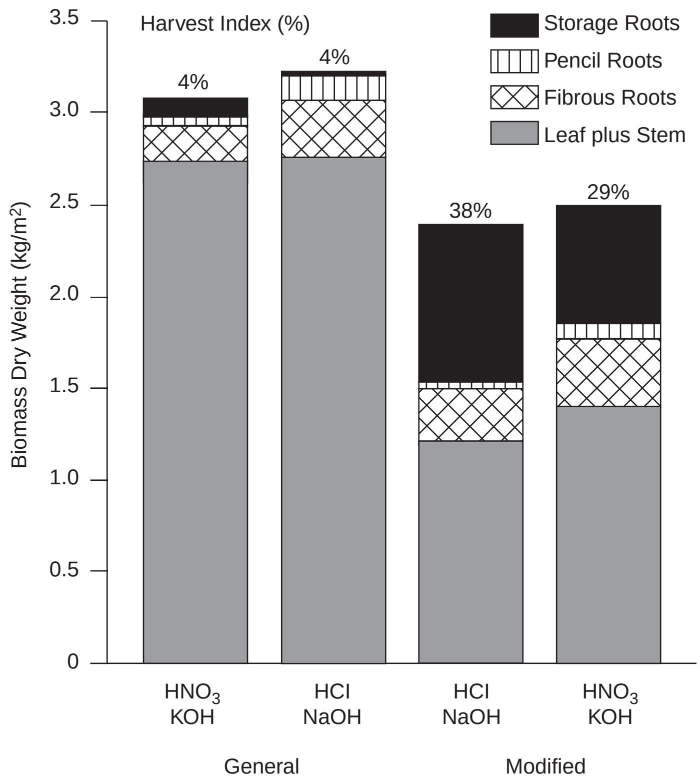
Participating Organizations: Dynamac Corporation (Dr. G.D. Goins) and Tuskegee University (Dr. D.G. Mortley and Dr. P.A. Loretan)



Biomass Partitioning Among Sweetpotato Plants Grown From Different Nutrient Management Techniques and pH Control Solutions

Plant Lighting Systems

Plants require a sufficient quantity and quality of light to produce food for space inhabitants. Innovative light sources are needed that provide radiation which fulfills photosynthetic and photomorphogenic requirements with regard to spectral output. Current lighting research for space-based plant culture is focused on development of advanced lighting technologies that have a high electrical efficiency and reduced mass and volume. Accordingly, light-emitting diodes (LED's) and microwave lamps are promising technologies that have several appealing features for applications in controlled environments. LED's radiate near the peak light absorption regions of chlorophyll while producing virtually no infrared radiation. Microwave electrode-less lamps use microwave energy to excite sulfur, which produces a continuous, broad-spectrum white light. Compared to conventional broad-spectrum sources, the microwave lamps are highly efficient and produce limited amounts of ultraviolet and infrared radiation. The work in the KSC Life Sciences Support program in association with the Advanced Life Support (ALS) program is currently exploring the feasibility of using LED's and/or microwave lamps as alternative light sources for plant biomass production.

Within the ALS program, salad-type plants (e.g., spinach, lettuce, and radish) represent crops that could provide a portion of fresh food as well as psychological benefits to the crew during long-duration space travel. Laboratory data generated with salad-type crops grown under LED's and microwave lighting will provide important information for the modeling and development of future ALS systems and testbeds. Work was completed with spinach plants grown under 9 different lighting sources for 28 days with a 16-hour light and 8-hour dark photoperiod. Three lamp banks represented broad-spectrum light sources: microwave,

Spinach Plants Growing Under an Array of 688-nm Red and 474-nm Blue LED's high-pressure sodium, and cool-white fluorescent. Testing also included six separate LED arrays that provided narrow-band radiation at 664, 666, 676, 688, 704, and 735 nanometers (nm). Each array contained single rows of blue LED's (474 nm) evenly distributed within the multiple rows of red LED's.

Key accomplishments:

- 1995: Completed four wheat and two *Arabidopsis* seed-to-seed experiments.
- 1996: Published a baseline report on seed-to-seed growth of superdwarf wheat and *Arabidopsis* under red LED's.
- 1997: Published research on photomorphogenesis and photosynthesis of wheat plants grown under red LED's.
- 1998: Awarded NASA Research Announcement (NRA) Solicitation 98-HEDS-01 grant to Dynamac Corporation for salad-type plant lighting research. Published four research papers on lighting research findings with LED's.
- 1999: Began experiments with salad-type plant growth under LED's and microwave lamps.

Key milestone:

- 2000: Complete salad-type plant growth studies under LED's and microwave lamps.

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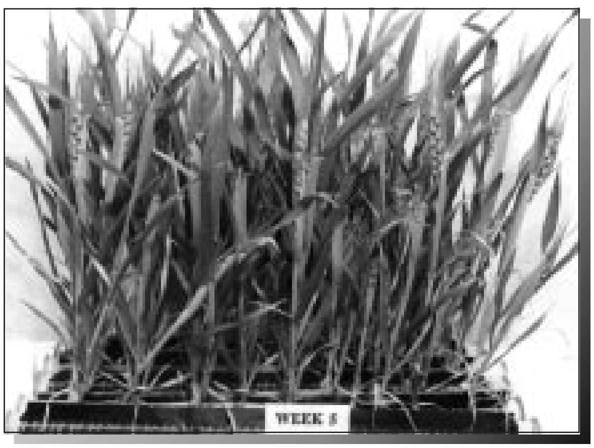
Participating Organization: Dynamac Corporation (Dr. G.D. Goins)

Evaluation of Two Microgravity-Rated Nutrient Delivery Systems Designed for the Cultivation of Plants in Space

There is a need for microgravity-based plant culture nutrient delivery systems (NDS's) for both bioregenerative life support systems and plant research functions. The provision of adequate levels of water (without causing waterlogging) and oxygen to the root zone is the most crucial issue deterring major advancements in this area. The dominance of the surface tension of water under micro-



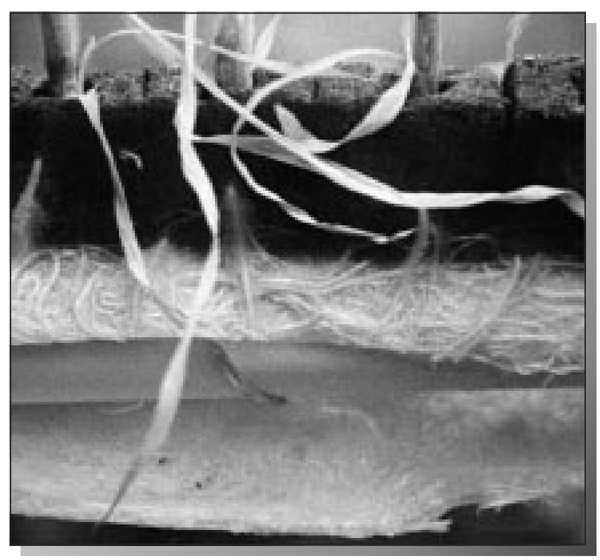
Forty-Five Wheat Plants Grown in a Growth Chamber for 5 Weeks on Five 30-cm-Long Porous Tubes (Seed heads are visible.)

gravity conditions has often led to either severe water-logging or excessive drying in the root zone. Consequently, differences in plant growth responses between spaceflight experiments and their ground controls are expected based merely upon differences in moisture distribution patterns between the two conditions. This project addresses the question of "comparability of environmental conditions" between the spaceflight and ground control experiments for both a porous tube plant NDS and a substrate-based NDS by employing three to six different wetness-level treatments for both these approaches. It is anticipated that different preset wetness levels than those used on Earth will be required to support optimal plant growth in space. Dry seeds will be loaded 3 days prior to orbiter liftoff, and the system will be initiated by the crew on-orbit. A minimum of 72 wheat (*Triticum aestivum*) seeds (for each of the two NDS's) will be imbibed and germinated on-orbit. Time-lapsed video recording of the plants will monitor growth over time. At recovery, the plants will be measured and tissues will be analyzed for gene expression and stress-associated metabolites.

Key accomplishments (1999):

As part of the past year's Definition Phase of the project, the following tasks were accomplished:

- Provided conceptual flow diagrams, environmental parameter specifications, estimations of flight crew interactions, and evaluation criteria



Base of the Wheat Plants as Initiated Within Foam Blocks on Top of a Porous Tube (A slice has been made along the root mass revealing the porous tube beneath.)

necessary to conduct the spaceflight experiment.
- Performed bench-top tests demonstrating the technical feasibility of the proposed approaches utilizing both porous tube and substrate-based nutrient delivery systems.
- Evaluated alternative experiment hardware platform options.
- Identified an overall flight project schedule incorporating KC-135 testing, hardware development, data for development of Shuttle documentation deliverables, and verification testing.

Key milestones:

- 2000: Identify basic hardware configuration options and develop and undertake science testing with prototype apparatus.
- 2001: Perform KC-135 testing of critical hardware designs and conduct a high-fidelity science verification test using the flight hardware configuration.
- 2002: Complete flight hardware fabrication and conduct a high-fidelity payload verification test using flight hardware.
- Conduct a spaceflight experiment on the Space Shuttle.

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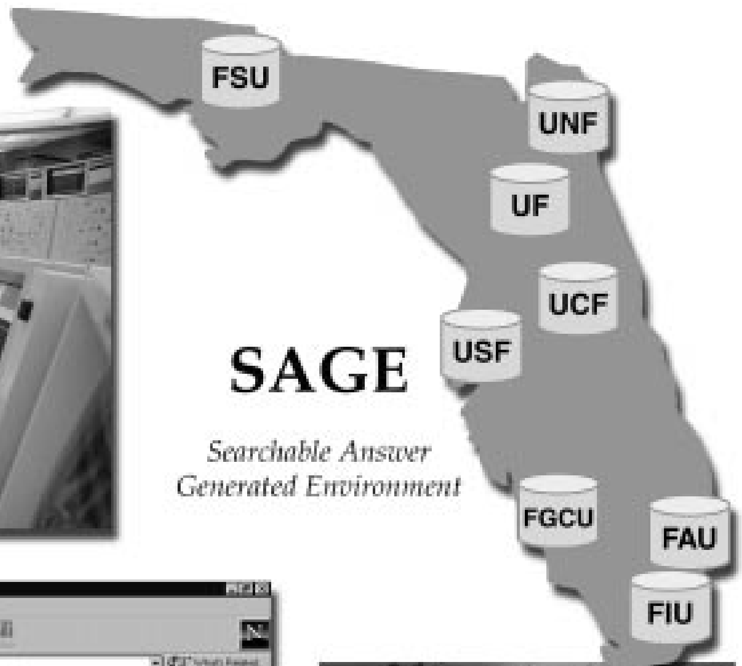
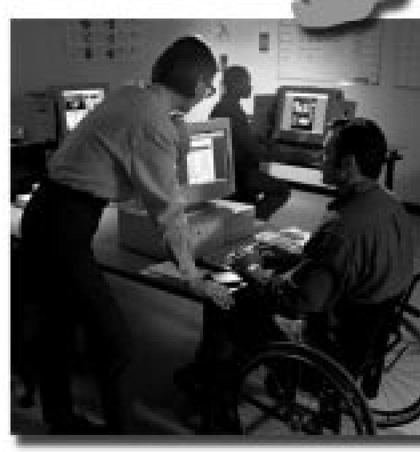
Workforce Development and Management Systems





NASA/KSC Technical Documentation System

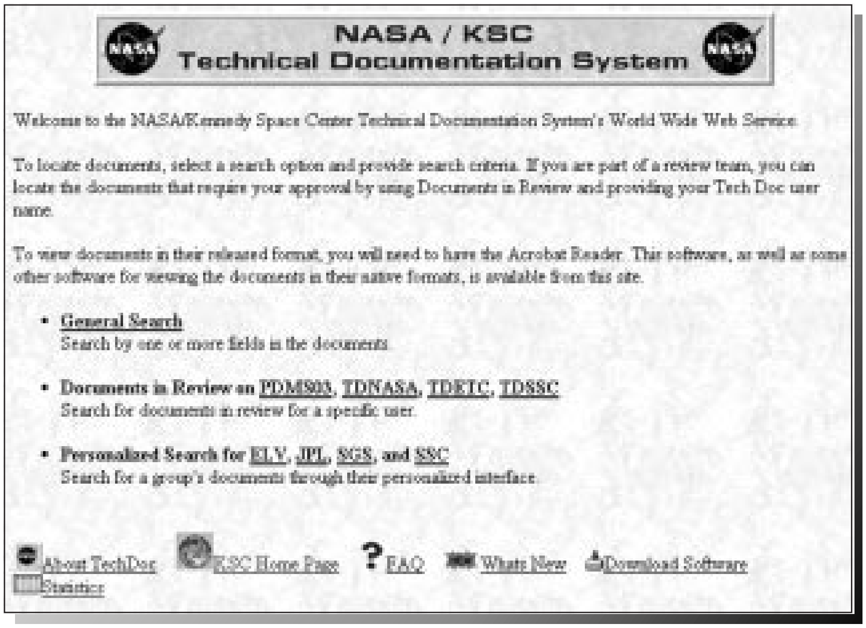
The NASA/KSC Technical Documentation (TechDoc) System was first developed to support the documentation requirements for the Payloads Processing Directorate at KSC because it did not have a centralized documentation repository. Electronic documents were stored on various platforms ranging from the personal computer to minicomputers. It was recognized that the organization needed to standardize its documentation development, storage, and retrieval tools and permit every employee read access to documents produced by the organization. In 1997, the TechDoc System was adapted to support the documentation requirements of Civil Service and support contractors at KSC and Stennis Space Center (SSC) to effectively manage their corporate knowledge and business processes. In 1999, the expandable launch vehicle (ELV) electronic library was implemented, and document-level security was added to restrict access of sensitive documentation to only those users with the proper privileges.

The significance of this project is that it provides the user community a means to maintain electronic documentation libraries that can be kept current and are easily accessible. The TechDoc System is a distributed document management system designed to allow for the management of any type document. TechDoc's search engine capability allows for multiple documentation systems to be included, thus capturing a broader set of document/corporate knowledge and making it available to the user community. In addition, the TechDoc System, originally developed by the Payloads Processing Directorate, was deployed for the ISO 9000 effort at KSC and SSC and for the ELV program. This saved the Government a substantial amount of time and money. The TechDoc System has been operational for 8 years and upgraded with advances in technology, such as the incorporation of the Java programming language for greater portability and the World Wide Web (WWW) for improved user interface access.

The TechDoc System tracks the number of WWW accesses. The average number of accesses per month is 96,000. There are over 88,000 (as of October 1999) documents in the TechDoc System.

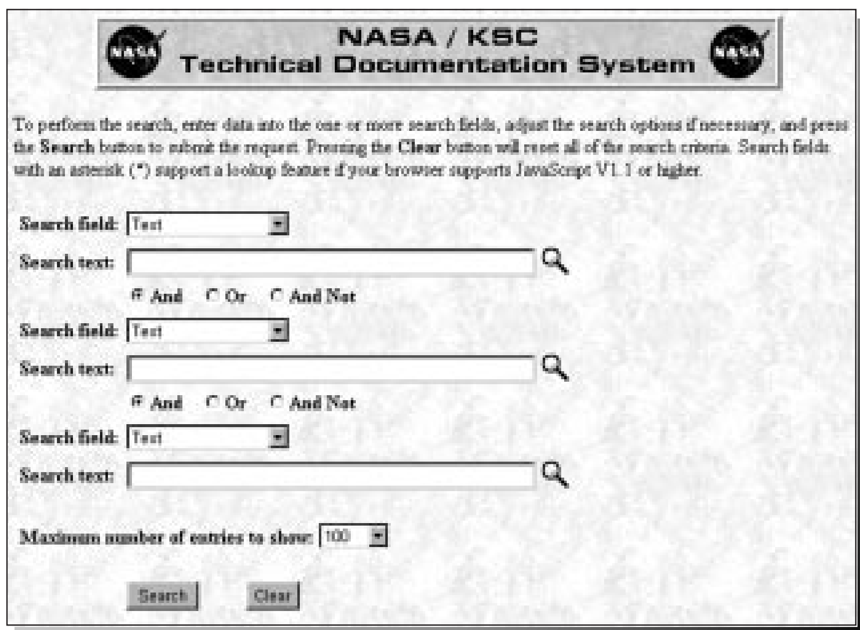
Key accomplishments:

- 1992: Delivered a Windows-based product for document management that was used only in the Payloads Processing Directorate (PDMS03).
- 1996: Developed and deployed a WWW interface for text search and retrieval as well as online review and approval of documents. This interface was developed for users to interface directly to the document repository from their own Web pages and is accessible by the nasa.gov domain.
- 1997: Developed and deployed an imaging system (TDARCHIVE) to support the archival requirements for the work authorization documents in the Payloads Processing Directorate. TDARCHIVE eliminates the need for microfiche and is accessible via the WWW interface by the user community. Deployed the NASA/KSC TechDoc System (TDNASA) to support the ISO 9000 effort as well as provide the repository for the KSC governing documents such as Kennedy management instructions. This system is used by KSC and is accessible by the nasa.gov domain.
- 1998: Deployed a new search engine that links the PDMS03, TDARCHIVE, and TDNASA systems for search and retrieval. The user can retrieve information from the WWW interface from one URL: *http://tdsearch.ksc.nasa.gov.* Deployed a database for SSC Civil Service and



contractor ISO 9000 Project Office document management.

- 1999: Implemented the ELV electronic library and added document-level security to restrict access to sensitive documentation to only those users with the proper privileges. Deployed a new database and Web-based search engine interface to support ELV Center of Excellence documentation efforts. Deployed TDRender, a timesaving automation tool that takes a copy of the native document, applies the ISO watermark, and creates the PDF file. Before this software was developed, the TechDoc document administrators performed this task manually, which was a time consuming process.



Key milestones:

- 2000: The current focus of the project is to develop and deploy a TechDoc 2.0 document management system that will be completely Web based and support distributed databases within the scope of the central search engine. The software will be developed in Java and will be able to be hosted on NT or UNIX. The TechDoc 2.0, phase 1, document management system is scheduled to be released in December 2000.
- 2001: Electronic review.

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Participating Organizations: All KSC NASA directorates and support contractors

Small Business Innovation Research (SBIR) Expert System

The Florida Minority Institutions Entrepreneurial Partnership Grant (FMIEP) is funding the development of a Web-based SBIR Expert System. This system was designed to optimize the time required to examine the potential eligibility for companies seeking SBIR funding. This system will prompt its users with a series of questions the answers to which will be used to evaluate the user's potential eligibility to be an SBIR winner (figure 1):

1. Is your company independently owned and operated?
2. Is your principal place of business located in the United States?
3. Is your company owned by at least 51 percent United States citizens or lawfully admitted permanent residents?
4. Does your company have less than 500 employees?
5. Has your proposed innovation (product or service) been patented or does it have patents pending?
6. Can your proposed innovation be patented or otherwise protected?
7. Are you planning to use the SBIR funding to conduct system studies, market research, commercial development of existing products or proven concepts, straightforward engineering design for packaging or adaptation to specific applications, studies, laboratory evaluations, and modifications of existing products without innovative changes?
8. Does your technology area align with any of the following research areas of interest to NASA?
   a. Aerospace technology
   b. Human exploration and development of space
   c. Earth science
   d. Space science
   e. Thrust areas
9. Is there a likelihood of your proposed technology having commercial application?
10. Has your firm been paid or is your firm currently being paid for essentially equivalent work by any agency of the Federal Government?

If the applicants meet the aforementioned criteria, they are prompted to fill in a Web-based form providing contact information. This system will serve as a tool to route companies that resemble the profile of potential SBIR winners to the corresponding SBIR assistance programs that the FMIEP consortium is creating in order to increase its chances of winning. This system will automatically send the contact information to a person in charge of assisting and encouraging these companies to put together a proposal to be submitted to the SBIR program for consideration. Moreover, the system will optimize time spent by the FMIEP consortium on assisting companies. Finally, the system will create a database of company profiles that will be used to generate mailings and announcements that will inform prospective SBIR companies of upcoming SBIR events and grant opportunities.

This project will benefit NASA, as it will promote the submission of SBIR applications by qualified companies. In addition, NASA will have access to a database of company profiles that

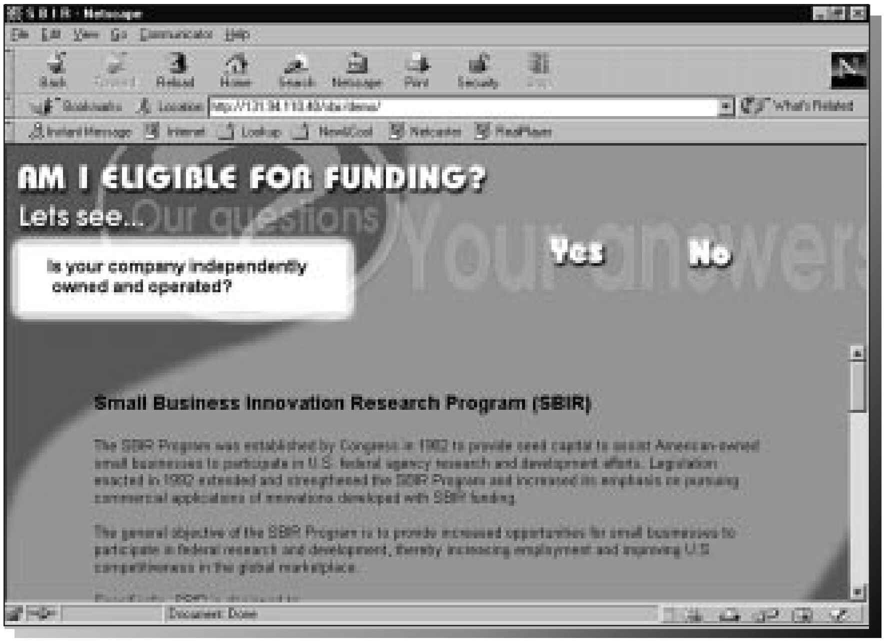

Figure 1. SBIR Questionnaire

resemble the profile of SBIR winners. When a candidate is not suitable, the system will provide the reason its company is not entitled to have SBIR funding (figure 2).

A prototype of this system can be viewed at: *http://sbir.fiu.edu*.

Key milestones:

- Design and development of the SBIR Expert System.
- Implementation of the system prototype.
- Testing of the system prototype.
- Rollout.

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Participating Organization: Florida International University (Dr. I. Becerra-Fernandez)

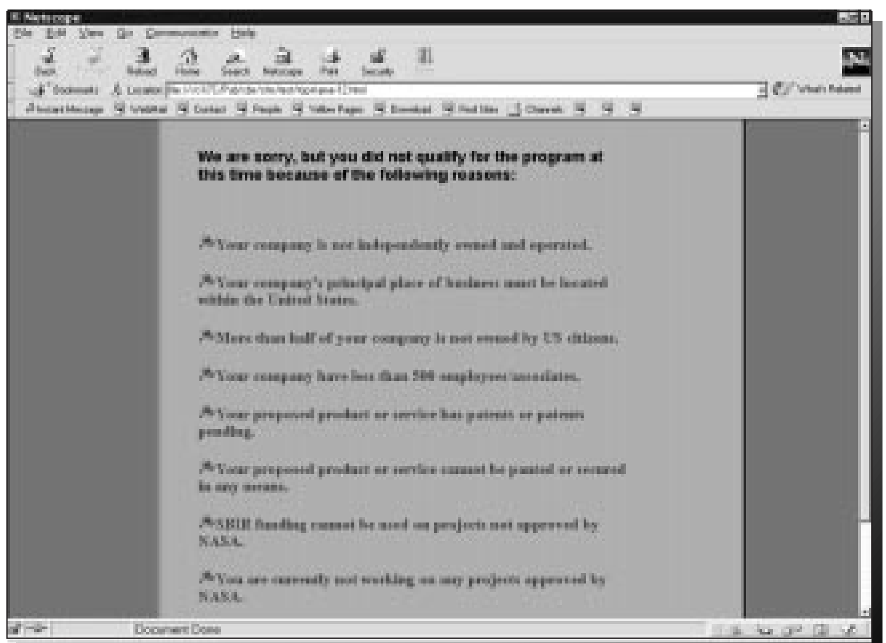

Figure 2. Reasons a Company Did Not Qualify for SBIR

Management Support Systems: Expert Seeker – A People-Finder Knowledge Management System To Seek Experts at KSC

The NASA Faculty Awards for Research program is funding the development of Expert Seeker, which is in the category of people-finder knowledge management system (KMS). Previous knowledge management studies at KSC affirm the need for a Centerwide repository that will provide KSC with intranet-based access to experts with specific backgrounds. Currently KSC is reorganizing from an operations center into a research and development center. This application currently under development aims to help locate intellectual capital within the Center at all educational levels. The Expert Seeker KMS stores competencies available within the organization including items that are not typically captured by the Human Resources (HR) applications, such as completed past projects, patents, hobbies, and other relevant knowledge. This people-finder KMS will be especially useful when organizing cross-functional teams.

The main interfaces on the query engine in Expert Seeker will use text fields to search the proposed data for keywords, fields of expertise, names, or other applicable search fields. The application will process the end user's query and return the pertinent information. The information will be collected from a conglomeration of multimedia databases and then presented as queried. The purpose of the Expert Seeker KMS is to unify myriad data collections into a Web-enabled repository that can be easily searched for relevant data. Prior to this project, there was no single point of entry into a unified repository that allowed identification of employees based on specific skills. Expert Seeker allows KSC experts more visibility and, at the same time, allows interested parties to identify available expertise within KSC. This people-finder KMS will help to identify a researcher's expertise within a discipline and to facilitate communication with a point of contact.

The development of Expert Seeker requires the utilization of existing data as much as possible. Expert Seeker uses the data in existing HR databases for information such as employee's formal educational background, the X.500 Directory for the employee point-of-contact information, a skills database that profiles each employee's competency areas, and the Goal Performance Evaluation System (GPES) (an in-house employee performance evaluation system). Furthermore, other related information deemed important in the generation of an expert profile that is not currently stored in an in-house database system can be user supplied, such as employee pictures, project participation data, hobbies, and volunteer or civic activities.

Recognizing there are significant shortcomings of self-assessment, it is suggested to use an increased reliance in technology to update employee profiles, which would place less reliance on self-assessed data (for example, the use of GPES to mine employee accomplishments and automatically update employee profiles). Typically, employees find it difficult to make time to keep resumes updated. Performance evaluations, on the other hand, are without a doubt part of everyone's job. Therefore, use of this tool, augmented with appropriate queries, would keep employee profiles up to date. Finally, a data mining effort of the document repository will also contribute to update employee profiles. Based on the assumption that authors of documents in the repository are subject matter experts, mining the electronic document repository will contribute to keeping employee profiles up to date in an unobtrusive way.

Key milestones:

- 2000: Appointment of the KSC Advisory Group. Literary review of people-finder industry models. Developed system specification. Development of the knowledge taxonomy. Design and development of the KMS. Implementation of the system prototype. Testing of the system prototype. Rollout.

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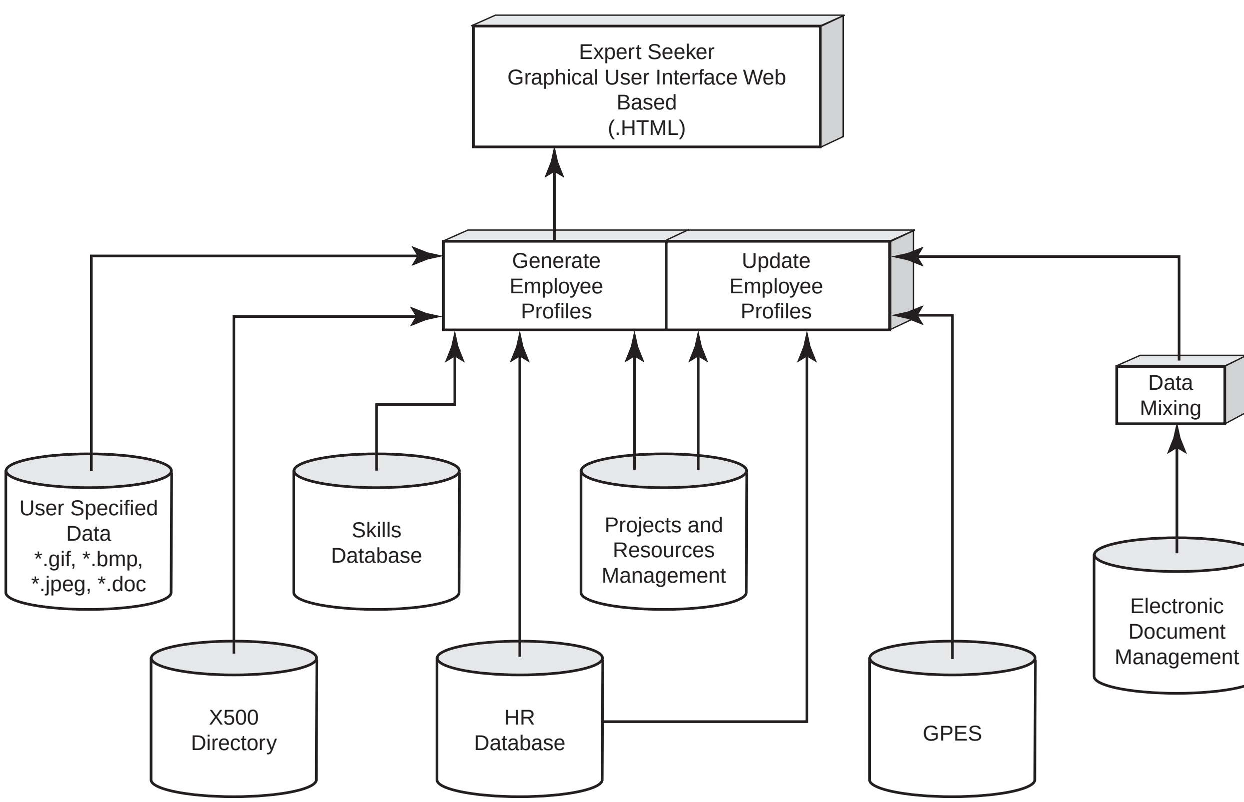
Participating Organizations: Florida International University (Dr. I. Becerra-Fernandez)

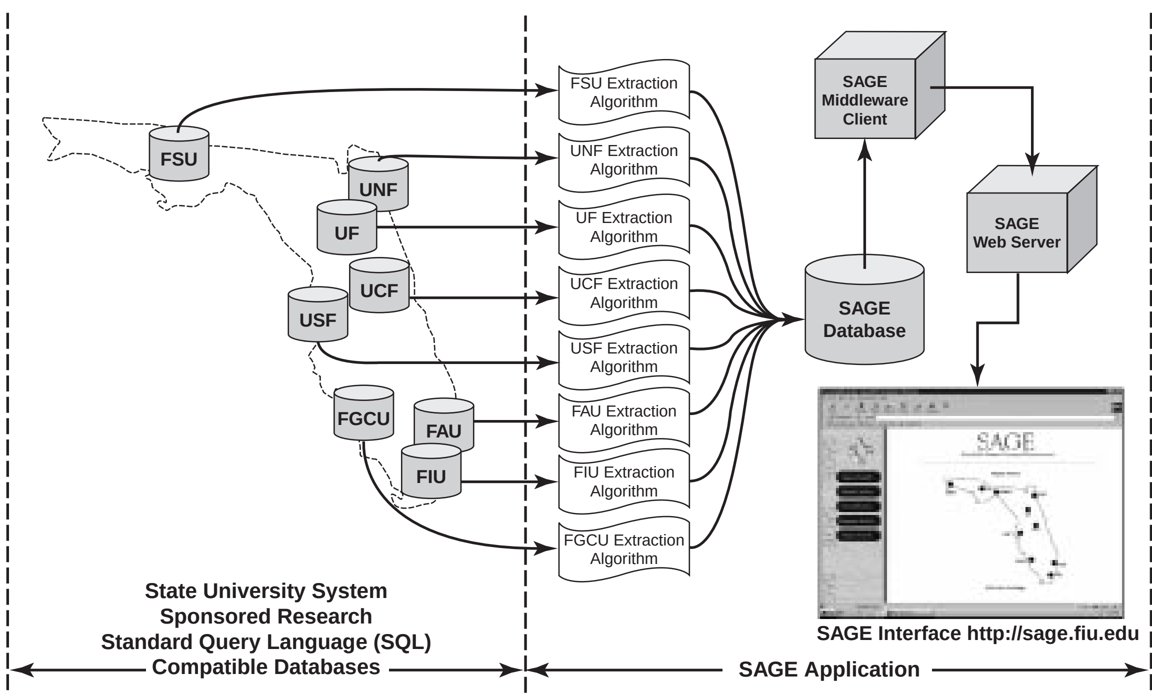


Expert Seeker Architecture

Management Support Systems: Searchable Answer Generating Environment (SAGE) – A Knowledge Management System To Seek Experts in the State of Florida University System

The NASA/Florida Minority Institution Entrepreneurial Partnership (FMIEP) grant funds the development of the SAGE, which is in the category of a People-Finder Knowledge Management System (KMS). The purpose of this KMS is to create a repository of experts in the Florida State University System (FL SUS). Currently, each state university keeps a database of funded research, but these databases are disparate and dissimilar. The SAGE KMS creates a single repository by incorporating a distributed database scheme that can be searched by a variety of fields, including research topic, investigator name, funding agency, or university. As KSC looks to develop new technologies necessary for the continuation of its space exploration missions, the need to partner with FL SUS experts becomes evident.

The SAGE system combines the unified database by masking multiple databases as if they were one. The desire of the project was to develop tools and techniques that would make managing these independent databases as seamless as possible. One of SAGE's advantages is that there is only one user point of entry at the Web-enabled interface, allowing multiple occurrences of the interface and giving the end user deployment flexibility. The main interfaces developed on the query engine use text fields to search the processed data. The application processes the end user's query and returns the pertinent information.



SAGE Architecture

SAGE consists of the typical university-sponsored research data. SAGE will give university researchers more visibility and, at the same time, allow interested parties to identify available expertise within the SUS. SAGE provides the following benefits: is a repository of intellectual capital within FL SUS; helps locate FL SUS researchers for collaboration with industry and Federal agencies; enhances communication and allows more visibility for FL SUS experts, making universities more marketable; and combines and unifies existing data from multiple sources into one user Web-accessible interface.

The development of SAGE was marked by two design requirements: the need to validate the data used to identify the experts and, at the same time, to minimize the impact of each of the university offices of sponsored research who collect most of the required data. For this reason, the data structure is taken in its native form and any necessary data cleansing is made at the SAGE server site. SAGE's strength also rests in its ability to search for experts by using a set of parameters or a proper name and to validate the data at the source. In other words, it is built upon a searching criteria recognized as a valid indicator of expertise.

SAGE is built upon the integration of the following technologies: (1) Cold Fusion™, an off-the-shelf rapid and integrated development environment; (2) Open Database Connectivity (ODBC), allows middleware to interface with the database; and (3) Verity's Search 97, performs the keyword search within the grant abstract field. (See the figure.)

The development of the SAGE database involved an initial design followed by incremental implementation phases. The initial design phase constituted a comprehensive survey of available tools and methodologies, followed by the selection of the most efficient approach to data storage and data retrieval. The two methodologies considered for data access were common gateway interface (CGI) and middleware. Cold Fusion™ was chosen as the middleware development environment because of its significant application strength and its demonstrated database interaction capabilities. Additionally, it provided the ability for secure transactions with Secure Socket Layer (SSL) technology, with the potential for strong encryption.

The implementation phase of SAGE involved the design of Cold Fusion™ modules, each with an assigned task. A robust server environment was set up along with a server operating system with remote user capabilities. Querying modules were used to provide search capabilities. Each query interface involved several modules that interacted with the database. Relational databases were chosen because of their efficiency and flexibility with data. The next step was alpha testing the interface both locally and remotely. The evaluation phase of the SAGE included heavy end-user testing and processing time optimization.

SAGE has been online since August 16, 1999, at http://sage.fiu.edu. One of the most important research contributions of SAGE is the merging of interorganizational database systems through the use of correspondence tables that function much like array pointers and allow compliance to differing database formats. Finding similarities between database fields is resolved through the correspondence tables, no matter how different their original formats are.

Key milestones:

- Development of algorithms that will facilitate the maintenance of SAGE in a more automatic fashion.
- Development of algorithms at both the SAGE server and at each university server. This effort requires the development of customizable features at each university server, the identification of the new records added since the last update, and following a "merge" or "update" transfer rule.
- Development of algorithms to select and cleanse transferred data over the Internet using the data dictionary. These fields will augment SAGE using the appropriate transfer rules.

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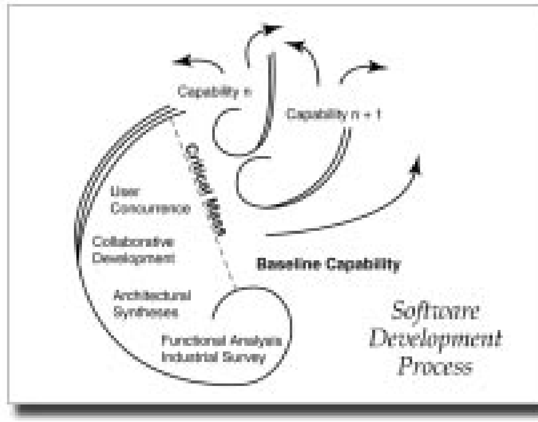
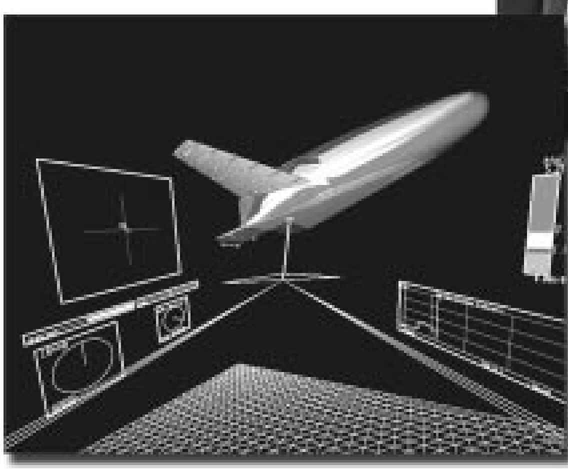
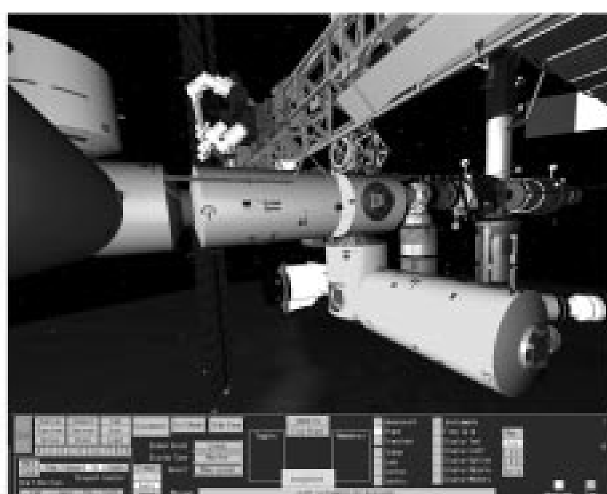
Participating Organization: Florida International University (Dr. I. Becerra-Fernandez)



Information Systems





KSC and NASA's Intelligent Synthesis Environment (ISE)

NASA's Intelligent Synthesis Environment (ISE) is an initiative directed toward developing state-of-the-art engineering tools, technologies, and methodologies. This effort is chartered by the NASA Administrator, Mr. Daniel Goldin, to develop and deploy the next generation of tools and infrastructure for use across NASA, industry, and academia, who are partners in the ISE initiative. The Collaborative Engineering Environment (CEE) is the deployment arm of this initiative. CEE efforts are focused on collecting, packaging, deploying, and commercializing existing "best practice" capabilities from across NASA, as well as state-of-the-art technologies from the ISE initiative. CEE provides integrated, tested, and supported systems, allowing the users of these systems to focus on their engineering activities as opposed to inventing engineering tools. Once deployed, these capabilities can also transition to the private sector where NASA and others can procure them as commercial tools and services.

KSC has deployed and is incorporating into its engineering culture the tools, technologies, and methodologies that comprise the current CEE. To date there are three Level 2 collaborative facilities and there are plans for three more. In addition, the existing three facilities have had Silicon Graphics ONYX-2 Infinite Reality systems installed to support CEE Level 3 Reality Conferencing. These are in use today for traditional collaborative roles including design reviews, integration of distributed teams, travel avoidance, and technology demonstrations. In addition, the rooms have supported nontraditional roles that include public outreach, distributed live educational programs, remote access to customer sites, launch readiness reviews, and collaborative application development. KSC future plans include continued use of classical collaborative capabilities supporting existing programs, as well as use of these facilities to gain efficient access to NASA's new programs and initiatives. These capabilities, specifically visual and reality conferencing, will allow engineering personnel to effectively participate in a wide range of design and development activities across the country and around the world.

These facilities provide for the distributed collaborative application of analysis and engineering tools. This allows distributed multidiscipline teams to interactively work with complex models, codes, and systems and to immediately view the results and new interrelationships between the data. Some of the benefits associated with shared modeling environments in efforts begun this year have been seen. Structures modeled to support the International Space Station (ISS) were updated and reused to support analysis for a new Space Shuttle Orbital Maneuvering System. In turn, these models will now be used to support operational assessments of multiple new and upgraded orbiter systems as well as integration testing for the ISS. The technologies utilized to support these activities, as well as the processes and some of the baseline models, are being enhanced and applied again to the needs of the expendable launch vehicle and payload carriers program to better support capacity analysis and further improve customer support capability. The results of all of these activities are going to be placed in a library for access by engineering and analysis teams across KSC and NASA.

One of the newer capabilities is the CEE Immersive Accommodation Environment (CEE Level 3). This allows the incorporation of analysis codes and capabilities into the shared synthetic environments. This physics-based set of tools provides a very high fidelity representation of the natural world as well as the space around it. The environment also allows the incorporation of multiple users in the simulation, each with local control over variables such as location, instruments, analysis codes, and location in the time stream. The environment is designed to simultaneously accommodate data sources as diverse as 20-year-old FORTRAN orbital dynamics codes and new Java applications. The first result is an application from the Langley Research Center that can identify and display the state of the ISS to multiple users, with all its components and articulating assemblies, precisely in the location expected at any point in the time stream.

KSC will be applying all these technologies to improve and enhance NASA's Spaceport operations. The goal is to represent KSC, complete with all the physical modeling, short- and long-range scheduling, and master planning systems. This representation can then be operated upon by intelligent capacity planning and analysis tools to provide rapid operational analysis of current and future space launch technologies. With these tools and capabilities, NASA expects to be better able to plan for and support its customer needs and to drive as much cost as possible out of the operational phase of a launch vehicle's life cycle. The result of the application of these CEE technologies and the more advanced follow-on ISE technologies will provide more efficient and effective access to space.

Key accomplishments:

- 1998: Installed and configured three CEE Level 2 (audio, video, data) facilities at KSC. Utilized systems to support Virtual Shuttle Processing Application development as well as Vision Spaceport Development.
- 1999: Upgraded all Level 3 facilities to support CEE Level 3 (added Synthetic Reality Capabilities). Utilized systems to extend Virtual Shuttle Processing Application, to support Shuttle Orbital Maneuvering System redesign efforts, and to model Payload Processing Facilities.

Key milestones:

- 2000: Begin development of Shuttle and Ground Processing Application with ISE and CEE. Begin local KSC ISE development activities. Develop Scheduling and Planning Interface to visualization environment.
- 2001: Provide high-fidelity multipart distributed simulations supporting NASA design missions. Provide Synthetic Process Test Facility.

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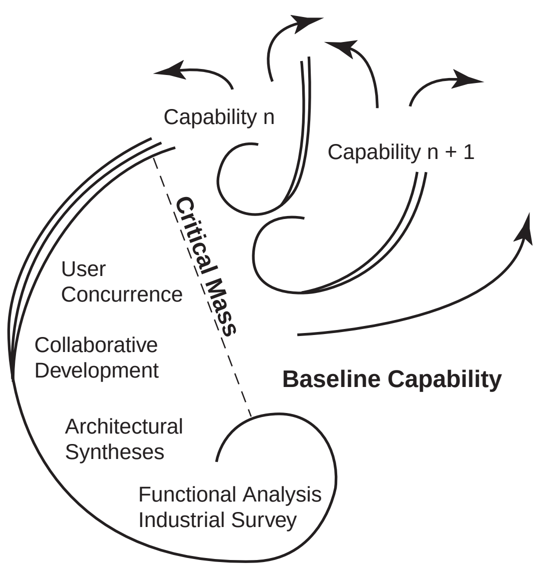
Participating Organizations: VA, MM, FF, PH, NN, Boeing, and United Space Alliance

Space Shuttle Ground Station Upgrade Using Collaborative Software Development and Sustaining Engineering

The Record and Playback Subsystem (RPS) ground station upgrade project was under development for several years using the standard software development method. The project underwent a systems engineering evaluation at the end of 1997. This evaluation revealed that after 7 years of development the software was less than 55 percent functionally complete and would require an additional 5 to 6 years of development to be complete totally. Management had anticipated software completion at the time of the evaluation. The challenge faced by project leadership was to deliver a complete and acceptable product for Shuttle processing in the shortest timeframe possible within budget constraints. In order to meet this challenge, a new software development process was developed called Collaborative Software Development and Sustaining Engineering. This method enables industrial software to be effectively leveraged by modifying the source code to meet mission needs while securing rights for the purposes of meeting mission objectives.



Software Development Process

An industrial survey revealed that no commercial off-the-shelf product was available that met the requirements delineated in the systems engineering project evaluation. Several candidates were evaluated but to no avail. Project leadership began exploring the vendor's willingness and ability to provide rights to the source code, collaborate on software development to modify their products, and develop additional capabilities required to complete the upgrade. Additional complexity was added to these negotiations because of the mission requirement to provide resident software sustaining engineering capability in support of Shuttle processing. The collaborator was required to provide software developers with training in their tools development environment and transfer software innovations through the technology transfer and commercialization program. After several weeks of evaluations, a tool (VMEWindows) and collaborator (ApLabs Inc.) were found that fit this criteria.

The first order of business was to establish a resident development environment and train developers in the VMEWindows development environment. Next, a spiral development process model was employed to perform modifications to the baseline product creating what was termed critical mass. Critical mass was defined as the point in the development process where enabling software, baseline functionality, and interface tools allowed multiple independent adjunct development activities. Four of these development efforts were software innovations submitted for technology transfer. In addition, the agreement for collaborative sustaining engineering fosters continued innovation and technology transfer while reducing recurring cost.

The following accomplishments are organized into four categories: (1) the four new capabilities developed to complete the upgrade project, (2) the cost and schedule savings over the status quo software development method, (3) the results of a delivered product attribute survey, and (4) the two innovations developed under the long-term collaborative sustaining engineering agreement.

Key accomplishments:

- Technological innovations:
  - Sbus Scramnet Interface for VMEWindows: Provides the capability to acquire and display data at an SBus workstation (Sun Sparc 20) from multiple real-time telemetry processors in a deterministic manner with minimal latency.
  - Stream Definition Flat File Import Capability for VMEWindows: Provides the capability to create an ASCII flat file from an SQL database and import this flat file into the stream definition of VMEWindows.
  - GPIB Board Setup and Control for Frequency Modulation (FM) Snapshot and Calibration: Provides the capability for automatic setup and control of both the discriminator and the switch to automatically produce an FM snapshot.
  - Datel 622 Digital to Analog Driver, Setup and Control: Provides the ability to load and control the Datel 622 analog-to-digital converter card to produce thermal array charts of data complete with loss-of-signal event indicators.
- Cost and Schedule Savings (actual over standard anticipated estimate to complete):
  - Software development costs were reduced by more than 60 percent over the standard development process.
  - Software development was completed in less than 20 percent of the time estimated to complete using the standard method.
- Product Attributes (delivered product versus standard anticipated product survey results):
  - Marketability: +/- 3 fold improvement.
  - Software Quality: +/- 4 fold improvement.
  - Maintainability: +/- 3 fold improvement.
- Follow-on Technological Innovations (developed after baseline upgrade software was complete):
  - Minor to Major Icon: Provides the capability to reconstitute minor frames of data into major frames to enable subcommutated data.
  - Real-Time Engineering Unit Dump: Provides the capability to review the current converted processing data in tabular form.

Key milestones:

- February 1998: Authority to proceed (Collaborative Software Development).
- March 1998: Collaborative development began.
- June 1998: Critical mass attained (adjunct capabilities development began).
- November 1998: Software development complete.
- December 1998: System integration and test complete.
- April 1999: First ground station installation complete.
- STS 93 and STS 96: Parallel mode operation processing and launch support.
- August 1999: Operational readiness review.
- September 1999: First ground station installation complete (project complete).

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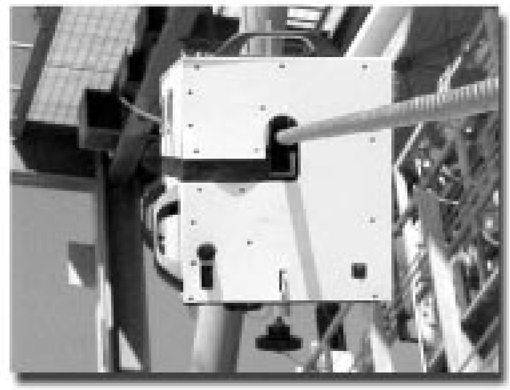
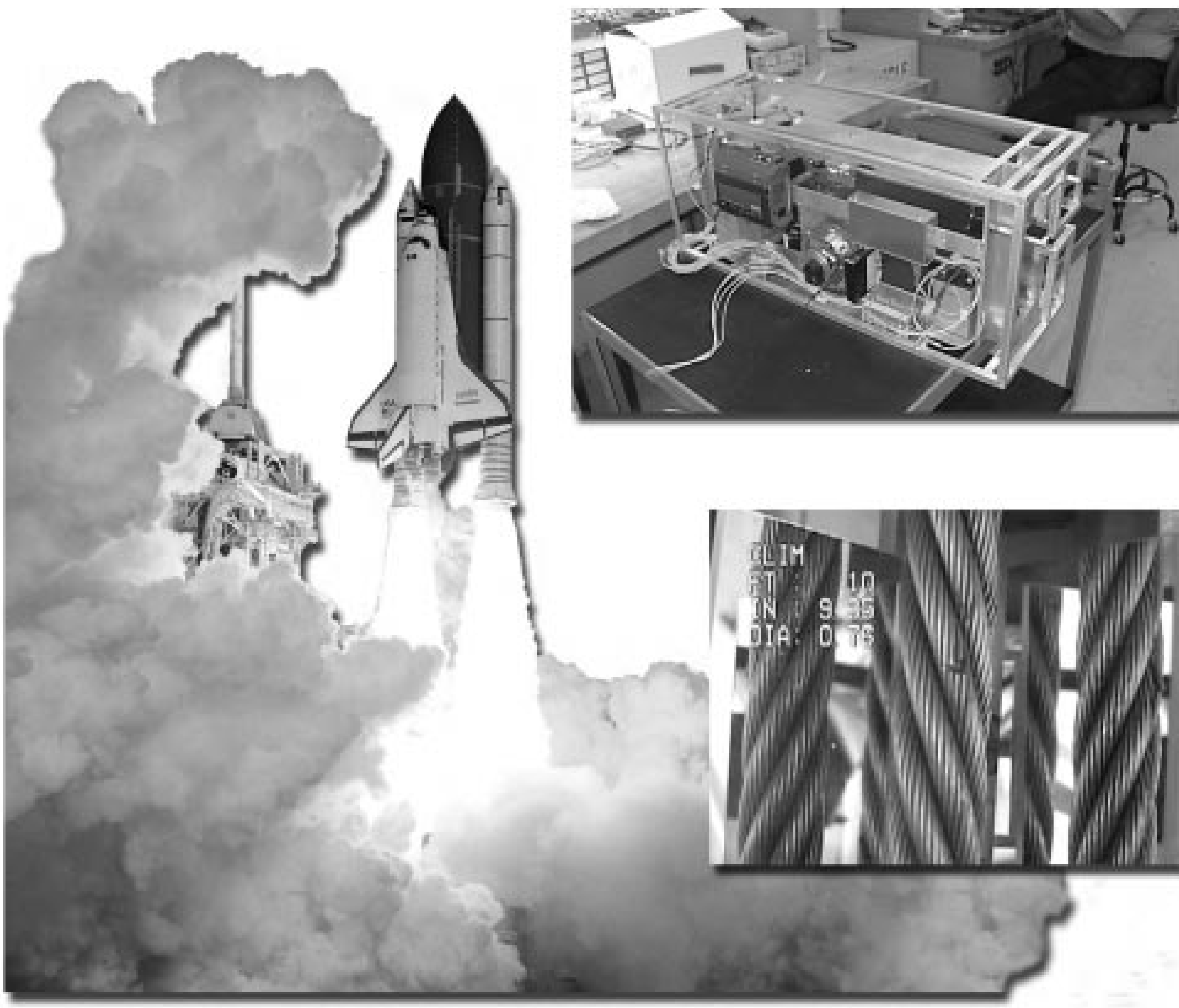
Participating Organizations: United Space Alliance (Dr. D. Mann and S. Prenger) and ApLabs Inc.

Shuttle Ground Station Controllers



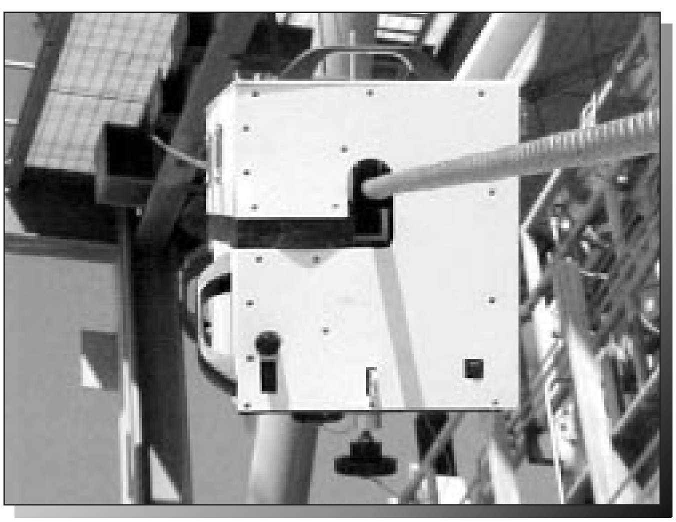
Safety and Mission Assurance



Cable and Line Inspection Mechanism (CLIM)

Biannual inspections of the seven slide-wire ropes used in the Emergency Egress System at Launch Pads A and B require inspection crews to visually verify the integrity of the wire ropes as the crews are lowered in the slide-wire baskets. Due to the type of ropes used as slide-wires (i.e., stainless steel with low carbon content), magnetic resonant devices normally employed to inspect the wire ropes are inadequate. This labor-intensive and time-consuming operation prompted a request to the Automated Ground Support Systems Laboratory to develop a stand-alone system for automated wire rope inspection. In addition, no method exists for inspection of the lightning wire ropes at each launch pad due to their inaccessibility.

The wire rope failures to be identified by the automated system, per the applicable operations and maintenance requirements document (OMRS File IV), are characterized by frayed strands, bird nesting, stretching, and corrosion. The wire ropes undergo periodic load testing and are rated for personnel by weighting the egress baskets with sandbags and sending them down the rope. Consequently, this is not a task for the automated system. The inspection teams rely on a visual inspection of the surface of the ropes with a cursory check of the rope diameter using a go/no-go gage every 10 feet. The targeted ropes were identified to have an inclination of no more than 45 degrees, a length of approximately 1,200 feet at 15 degrees, and a diameter of 1/2 to 3/4 inch.



CLIM Unit Mounted on a Wire Rope

A production unit was built that provides a real-time video image and diameter of the wire rope under test to an operator at the control station. Testing on a wire rope similar in angle and diameter to the egress system wire ropes shows a duration of 1,400 feet using 12-volt lead acid batteries. Data showing cable diameter is recorded to permanent memory in the on-board computer and can be downloaded to the control station posttest. Video is taped for playback using an off-the-shelf video recorder. An acceptance test on the Launch Pad B slide wires is currently targeted for February 2000.

Key accomplishments:

- 1998: Tested the prototype unit. Manufactured the production unit.
- 1999: Designed and built a production unit.

Key milestone:

- 2000: Assemble, test, and turn over the production unit.

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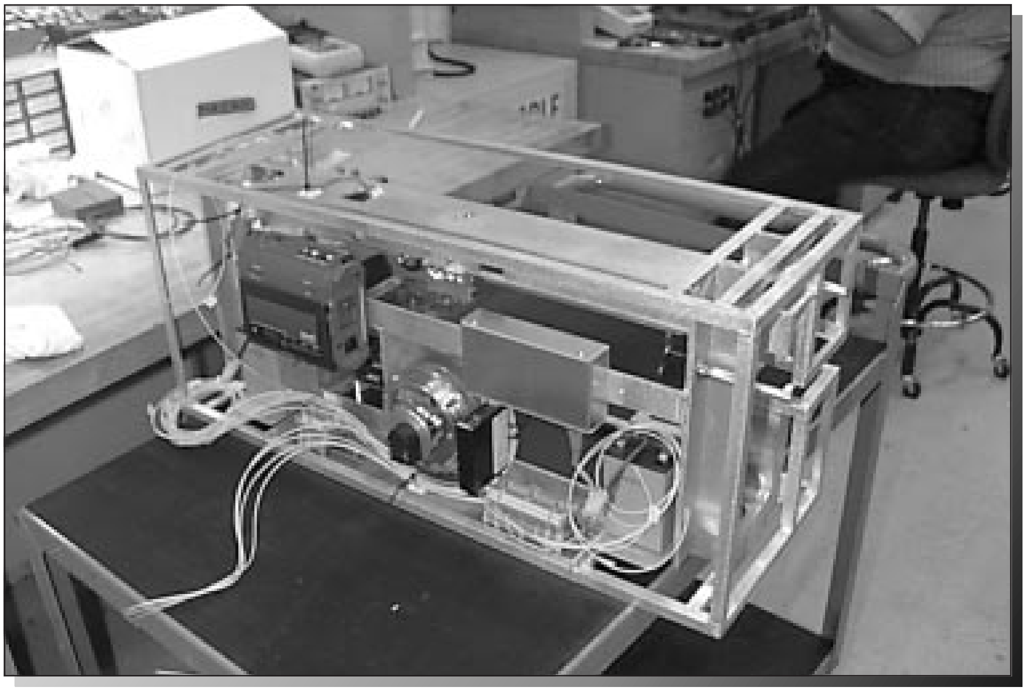
Participating Organizations: NASA MM-G3 (T. Bonner and M. Hogue), NASA PK-J (K. Nowak), NASA MM-E (J. Richards-Gruendel and L. Parrish), and United Space Alliance (G. Hajdaj and M. Olka)



CLIM Unit Frame Without Covers

Defect on a Wire Rope